

AD-784 368

**SHIP RFI SURVEY PROCEDURE FOR HF
FREQUENCIES, A TASK UNDER THE SHIP-
BOARD EMC IMPROVEMENT PROGRAM (SEMCIP)**

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21 June 1974

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AD-784368

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NELC Technical Document TD 336	2. GOVT ACCESSION NO. ---	3. RECIPIENT'S CATALOG NUMBER ---
4. TITLE (and Subtitle) SHIP RFI SURVEY PROCEDURE FOR HF FREQUENCIES, A task under the Shipboard EMC Improvement Program (SEMCIP)	5. TYPE OF REPORT & PERIOD COVERED ---	
	6. PERFORMING ORG. REPORT NUMBER ---	
7. AUTHOR(s) W. M. Chase	8. CONTRACT OR GRANT NUMBER(s) ---	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Electronics Laboratory Center San Diego, California 92152	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS O&MN NAVSHIPS (NELC J547)	
11. CONTROLLING OFFICE NAME AND ADDRESS ---	12. REPORT DATE 21 June 1974	
	13. NUMBER OF PAGES 86	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) ---	15. SECURITY CLASS. (of this report) UNCLASSIFIED	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE ---	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) ---		
18. SUPPLEMENTARY NOTES ---		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Ships Radio-frequency interference Shipboard EMC Improvement Program (SEMCIP) Intermodulation <div style="text-align: right;">Reproduced by NATIONAL TECHNICAL INFORMATION SERVICE U. S. Department of Commerce Springfield, VA 22151</div>		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <p>This document provides a method of obtaining the most meaningful information possible regarding the potential RFI situation on a ship from data taken under severe time restrictions. Discussion is limited to the HF band, 2-30 MHz, but similar tests conducted at other frequencies will provide results of equal merit. Since the effect of RFI on reception capability, rather than the phenomena causing it, is being investigated, the ship's receiving subsystem is used to monitor RFI signals with a minimum of special equipment.</p> <p style="text-align: right;">(continued)</p>		

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The fundamental question is, "How great is the potential for RFI due to intermodulation interference signals on this specific ship?" It is chiefly asked (1) during sea trials of new construction, (2) prior to a scheduled shipyard availability for an operational ship, and (3) just after work in a shipyard has been completed.

The method does not simulate operational conditions by activating a majority of the available transmitters simultaneously. By monitoring individual interference signal levels when only two transmitters are operating, it provides accurate predictions of the severity of operational interference conditions. If RFI potential is high, the most important source can be determined. If several sources are found, they are automatically ranked in order of importance.

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I BACKGROUND

This document is written to provide a clearly defined method of obtaining the most meaningful information possible regarding the potential RFI situation on a ship from data taken under severe time restrictions. Discussion will be limited to the HF band, 2 to 30 MHz. Similar tests to get results of equal merit can be conducted at other frequencies. Since the effect of RFI on the ship's reception capability is being investigated rather than the phenomena causing RFI, the ship's receiving subsystem will be used to monitor RFI signals with a minimum of special equipment.

As the discussion progresses to the details of how the survey is made it will be found that key concepts depart radically from tradition. The techniques were derived from a very thorough investigation of intermodulation fundamentals. They have been proven in the field and represent much more effective and reliable procedures than any previously employed.

The fundamental question is, "How great is the potential for RFI due to intermodulation interference signals on this specific ship?" There are three circumstances for asking this question: during sea trials of new construction; just prior to a scheduled shipyard availability for an operational ship; just after work in a shipyard has been completed. (In addition, a ship's communications people can also conduct these tests at any time to assure themselves communications reliability is not hindered by RFI.)

It should be clearly understood the survey does not attempt to simulate operational conditions by activating all or most of the available transmitters and then drawing conclusions from the very complicated interference spectrum. The survey's worth comes from monitoring individual interference signal levels when only two transmitters are operating simultaneously. Accurate predictions of the severity of operational interference conditions are readily obtained during the RFI survey. In the event RFI potential is high, immediate steps can be taken to determine the most important interference source. If several sources are found, they are automatically ranked in order of importance.

II REQUIRED EFFORT PRIOR TO A SURVEY

During any serious discussion of general RFI problems aboard ship three broad areas where interference can occur will be referred to, namely, the transmit system, the receive system, and the antennas plus local environment. At a recent workshop conference on RFI it was pointed out interference difficulties in each of these areas must depend on design, installation, and maintenance. So it follows logically an RFI survey on a specific ship must depend on the thoroughness with which preliminary investigations or analyses are conducted.

From detailed knowledge of the types of transmitters to be used, their inherent characteristics liable to cause RFI, the selectivity characteristics of equipments between transmitter output terminals and the antenna feedpoints, and the isolation between transmit and receive antennas, a reliable and quantitative analysis can be made regarding the available power magnitude of interference signals appearing at the receiving antenna.

From detailed knowledge of the types of receivers to be used, their inherent vulnerability to RFI generation in receiver circuitry due to local transmissions, the selectivity characteristics of equipments between receiver input terminals and the antenna feedpoints, and the isolation between receive and transmit antennas, a reliable and quantitative analysis can be made of conditions for generating significant interference in the receivers.

In the event these two analyses show interference circumstances to be unacceptable during operational use of the communications system, changes will have to be made in the equipments until the combination of characteristics and conditions of operation do allow an acceptable situation. Even if no equipment changes are possible, the analyses will provide justification for rigid limitations for operating the system to avoid equipment-generated RFI signals.

The analyses, however, utilize performance data which are the result of design for each of the interrelated equipments in the communication system. Thus, if the analyses results are relied on to be an accurate indication of what will actually happen on a given ship, it must be assumed the installation of the equipments is done correctly. But skepticism is an important part of any RFI investigation. In order to be sure the apparently acceptable performance will occur when the equipment is on the ship, some sort of inspection or series of tests must be made to find out whether some unknown difficulty during installation has degraded the communications system—or more accurately, the receive system's low error rate reception of incoming traffic.

The subject of this section, then, is really concerned with those things which are comparatively easy to control. It is most important to assure controllable circumstances liable to contribute

significantly to the overall RFI situation aboard ship are indeed controlled. There are enough possible sources of interference which cannot be controlled or predicted outside the equipments. The business of the RFI survey is to observe the effects of such sources and eliminate them, if necessary. But when a survey is conducted with little or no prior concern for the generators of RFI signals resulting from design or installation of the communications system components themselves it is likely monitoring interference signals from uncontrollable sources will be impossible. Intermodulation interference appears on the same frequencies independent of source; therefore, an investigator finds it extremely difficult to distinguish between individual signals contributing to the sum total affecting a victim receiver set on any given frequency.

Note the emphasis on intermodulation. Other familiar difficulties afflicting reception of off-ship signals are more obvious. These include receiver front end burnout, desensitization and transmitter fundamental spectrum signature. (Cross-modulation is a form of receiver-generated intermodulation, requiring only one transmission at a frequency close to the receive frequency rather than two or more.) Because of their more obvious nature they are better understood and more readily avoided. An RFI survey in intermodulation interference involves the much less obvious causes of reception difficulties.

III DEPENDENCE ON SHIP EQUIPMENT PERFORMANCE

A comment has been made about the RFI survey's investigating the potential for intermodulation interference by observing the level of signals with a ship's receiving system. It is most important for the receivers and other components to be operating at design capability. The RFI survey team should not be required to, in effect, conduct a series of checks evaluating the performance of the receiving system before being able to begin the survey. Only a limited time is available for the survey. Any portion spent in equipment checkout means less time for the RFI tests, and ultimately the worth of the survey results suffers.

Similarly, the transmit system's performance must be reliable before an RFI survey is attempted. Instability of transmitter power output or frequency under continuous CW operation needed during the survey can cause disastrous damage to the results of the survey as well as greatly increase time spent making it. Rapid changes in transmitter frequency and in patching transmitters to multicoupler/antenna combinations are necessary during the survey. Delay due to these changes must be held to a minimum. Since the survey emphasizes monitoring high order intermodulation signals, it is mandatory that the actual frequency of each CW transmission be known accurately. Difficulty in this aspect of the survey stems directly from the confusion about a single sideband transmitter's carrier frequency and the frequency of the audio tone generating the CW signal.

IV DEPENDENCE ON REMOVAL OF JUNK

As one realizes how the RFI survey represents a means of accurately predicting the intermodulation interference situation when the ship is on an operational mission, it is readily understandable how important circumstances for the survey are. The previous section dealt with the performance of receiving and transmitting equipments. Equally important to the accuracy of the survey's results is the condition of the ship's topside areas while the tests are run.

Especially during surveys during new construction sea trials, and to a lesser degree after a shipalt, the data obtained are likely to be misleading or meaningless unless the typical items of shipyard junk scattered around topside are removed. Most of this junk—useful as it may be to the work of the shipyard, electronically it must be considered as junk—is made of metal. So, when the survey transmissions are made, the junk is liable to excitation by currents at transmitter frequencies. Because of the helter-skelter arrangement of the metal junk parts, poor contacts will exist between them or with the ship. It would not be surprising if the monitoring of signal levels at high order intermodulation frequencies discovered strong interference. This, of course, would trigger a search for the worst sources. Much time would be wasted if these sources were found to be due to shipyard junk and not a device integral to the ship itself. Indeed, the RFI survey would have to be postponed until the ship's topside condition more nearly matched that considered to be normal under operational conditions.

V DEPENDENCE ON EMCON DURING SURVEY

The RFI survey is made with but two CW transmitters operating simultaneously to maintain rigid control of the intermodulation signals generated in the nonlinear sources excited by currents at the transmit frequencies. With only two transmitters active the calculations necessary to determine accurately the orders of the intermodulation signals monitored are comparatively easy. However, the calculations become much more complicated and time consuming with the addition of even one more simultaneous local transmission. Therefore, it is very much better if no other transmissions but the two required for the survey are made during the RFI investigation.

An important advantage of the CW test transmissions is the CW intermodulation signals generated in the RFI sources. If a third transmission is made with a more complex modulation mode—FSK, data, MUX, etc.,—that modulation will be superimposed on the intermodulation signals being monitored by the RFI investigator, alerting him to the breach of transmitter control.

Another reason for the necessity of transmitter control during an RFI survey is the effect on intermodulation signal levels caused by the additional excitation power in the RFI sources. Accurate evaluation of interference level and intermodulation order data becomes more difficult and less reliable.

The previous statements apply most significantly to unwanted additional transmissions in the same frequency band as the two CW test transmissions. If, however, it is necessary to conduct UHF communications while an HF RFI survey is in progress, there is less possibility of contaminating the survey data than if the non-survey transmissions were also at HF. It follows that, if the usual two HF MUX transmissions supporting the duplex ship/shore PAPA communications are required during a scheduled HF RFI survey, a reliable set of data is impossible. Under these circumstances the survey would deteriorate to the much more restrictive use of the PAPA transmissions as excitation for the RFI sources; CW test transmissions would then be unnecessary and actually unwanted. Investigating the variation of RFI with change in transmit frequencies and antennas must then await PAPA transmission changes caused by propagation conditions on the ship-to-shore path. Another problem associated with this modified survey procedure is the greater difficulty in calculating intermodulation signal orders with mid-band frequencies of the MUX modulated transmissions.

VI MINIMUM REQUIRED TOOLS

To successfully conduct an RFI survey the following tools are used. The list is in order of importance.

- (1) 10-digit electronic calculator
- (2) 50 ohm, 1 dB per step, attenuator
- (3) Damped audio meter
- (4) Portable DF receiver
- (5) Signal generator
- (6) Noise generator
- (7) Frequency counter

The first three items directly assist survey data taking. The last three items are used only to increase the investigator's confidence that basic factors are under control. The fourth item is obviously needed to locate worst RFI sources when survey results prove the ship's intermodulation interference potential to be great enough to demand source location.

(1) A high quality, reliable electronic calculator performs the considerable number of arithmetic steps involving the two test transmission frequencies and the intermodulation frequencies monitored by the receiver. Although not absolutely necessary, the calculator capacity should be 10 digits rather than 8. The Hewlett-Packard Model 35 is an excellent choice. (As a matter of convenience the operator should train himself to manipulate the calculator with the hand he does not use to write with.)

(2) The receiver noise power in the monitoring receiver's information bandwidth, usually 3 kHz, is relied on as a reference for measuring intermodulation signal level. A variable attenuator at the receiver's input terminals controls the relationship of RFI signal power to receiver noise power. It is then unnecessary to change the receiver audio or RF gain controls. As long as it is maintained throughout once decided on, the actual signal-plus-noise to noise ratio is not important. (3 dB indicates equality of signal and noise powers. 6 dB results when signal power is 3 times noise power. 10 dB shows the signal to have 9 times the noise power.) A series combination of Hewlett-Packard 355C and 355D attenuators provides a maximum of 132 dB—much more than needed except when checking receiver noise alone—in increments of 1 dB. With the attenuator set for a 3 dB S + N/N the ratio of signal to receiver noise powers is the attenuator reading. This method of signal control is forced by the unfortunate fact that many Navy communications receivers do not have an AGC OFF switch. Therefore, it is necessary to keep the signal level below the AGC threshold to get accurate data.

(3) From the previous discussion it is obvious the audio meter must be calibrated in dB. In addition, there must be a slower-than-normal time constant to provide a steadier meter reading for noise and rapidly varying signals. This damping is most easily obtained from an internal capacitive shunt of several hundred microfarads across the d.c. meter terminals.

(4) The value of the RFI survey rests directly on the fact that the higher the order of the significant level intermodulation signal monitored the greater the potential for unacceptable interference during operational communications. Also, the worst of an unknown number of intermodulation sources is the generator of the highest order signal. Therefore, location of the worst source is made easy by using simple direction-finding at the frequencies where highest order intermodulation signals occur. Portable receivers with directional antennas and manual gain or signal level control first pinpoint the area of the worst source and then locate the source by working in that area. (Discreet judgment in the choice of the two transmit frequencies forces the occurrence of high order intermodulation signals in the standard AM broadcast band, 535 to 1635 kHz. Modified transistor radios of good design and construction, preferably remounted in an effective shield can and provided with a balanced loop antenna, make very acceptable portable direction finding equipments. A bonus of DF-ing at such low frequencies comes from the lack of ship structures with appreciable electrical length; at higher frequencies parasitic action of structures tends to smear sharp nulls required for precision DF work.)

(5) If it is desired to establish the equivalent level of receiver-generated intermodulation—or cross-check the level of interference received from other sources against the previously described $S + N/N$ technique—a good quality signal generator (equivalent to Hewlett-Packard Model 606B) is used as a substitute signal source. Signal level power, available or received, can be found by adjusting the signal generator output to the same condition in the monitoring receiver as observed with the actual interference signal.

(6) A 50 ohm source of white noise, flat across the entire HF spectrum and capable of 20 dB above thermal noise output, plus a 1 dB per step 50 ohm variable attenuator allows the investigator to be sure of the monitoring receiver's noise power by checking the sensitivity in terms of noise figure.

(7) Doubt concerning the actual frequencies of the two CW test transmissions is removed by checking them at the monitor receiver location with a reliable frequency counter. Another use of the counter is to set the signal generator frequency more accurately.

VII JUSTIFICATION FOR TWO CW TEST TRANSMISSIONS

In Section V the need for restricting transmissions to the two test transmissions is mentioned. The importance of this point becomes clearer after reference to some pertinent information from the mathematics involved.

There are two reasons why only a single CW test transmission might be considered sufficient to conduct an RFI survey. The same sources capable of generating intermodulation plus harmonic interference signals, when two or more transmissions are made simultaneously, produce only the harmonics of a single transmission frequency. Harmonics, then, are correctly regarded as special cases of the intermodulation phenomenon. But harmonics of a test transmission at 2 or 3 MHz will be restricted to the 15th or 10th within the HF band. Obviously, monitoring the harmonics of transmissions above 10 MHz will be limited to the 2nd. Furthermore, an RFI investigator wants to observe high order intermodulation signals within or below the HF band. So, in spite of the apparent advantage for simplifying the survey procedure, there must be a minimum of two simultaneous test transmissions if the potential for interference at likely receive frequencies in the same band as the transmit frequencies is to be truly established.

Without becoming too involved now with the details of the calculations (see Section XIII), the general steps can be listed which lead to the correct order for a specific intermodulation signal caused by two transmissions.

- (1) Find the greatest common factor between the two transmit frequencies.
- (2) Divide the suspected intermodulation signal frequency by the greatest common factor. (If the quotient is a whole number, the signal is proven to be due to intermodulation between only the two test transmissions.)
- (3) Calculate the intermodulation label coefficient for each of the two transmit frequencies; their sum, sign ignored, indicates the lowest order for the intermodulation signal that will occur at a frequency equal to the greatest common factor.
- (4) Similarly, calculate the intermodulation label coefficient for each of the two transmit frequencies; their sum, sign ignored, indicates the next lowest order to the obviously lowest "zeroth order" at zero frequency or DC.
- (5) Using the results of (3) and (4) calculate the coefficient for each of the two transmit frequencies; their sum, sign ignored, describe the lowest order for the specific qualified intermodulation signal under consideration.

[When three test transmissions are active simultaneously, the first four steps are performed for each of the three possible transmit frequency pairs. Then, lowest order intermodulation labels for both the intermodulation frequency and the remaining transmit frequency must be calculated in terms of each pair. Next, calculation of lowest order "three frequency" labels are obtained for the intermodulation signal under consideration using results of the preliminary calculations for each pair. The lowest order of these three candidates is the solution. For more than three simultaneous transmissions the procedure is very similar; an indication of the increased complexity comes from knowledge of how many transmit frequency pair combinations are possible.

If the three transmit frequencies share the same greatest common factor, many "two frequency" high order intermodulation signals of significant level will be overwhelmed by the stronger "three frequency" intermodulation signals of much lower order occurring on the same frequencies.]

VIII CHOICE OF TEST TRANSMISSION FREQUENCIES

The ideal, but impractical, situation for test transmission frequencies would be the uninhibited use of any pair satisfying the interrelationships affecting (a) the separation between adjacent qualified intermodulation frequencies of any order and (b) the limitation set by the maximum possible value for the lowest order on a qualified frequency.

The greatest common factor between the test transmission frequencies plays a pivotal role in both of these counts. As mentioned in a previous section, the greatest common factor is the smallest qualified intermodulation frequency. It is also the increment between all adjacent intermodulation signals. Because the usual intermediate frequency bandwidth of a monitoring receiver is 3 kHz, the desirable minimum value for the greatest common factor is something greater than that, say 4 or 5 kHz.

Without further consideration it would seem the larger the greatest common factor the better. However, there is the somewhat counteracting influence of the second interrelationship maximum possible order. The quotient from the division of the sum of the transmit frequencies by twice the greatest common factor (with the possible fractional remainder of $1/2$ ignored) represents the maximum value for the lowest intermodulation order at qualified frequencies up to the harmonic of the least transmission frequency equal to the quotient. Thus, if the greatest common factor is too large, it may be impossible to observe a high order significant level intermodulation signal; not because it doesn't exist, but because it occupies the same frequency as a much stronger signal of lower order.

(If maximum order possible is the 11th, but the highest detectable order is actually the 31st—a positive indication of high RFI potential—the 31st order will never be seen by the monitoring receiver. All qualified intermodulation frequencies will be supporting lowest orders from 2nd through 11th in addition to the possibly very important higher orders.)

The RFI investigator is forced to check both greatest common factor and maximum value for lowest intermodulation order before he accepts any available pair of survey test transmission frequencies.

An additional difficulty is encountered during the choice of test frequencies, because there are only a limited number of allocated transmit frequencies in the pool controlled by a Communications Area Master Station. Some relief can be found in either juggling the test transmitter carrier frequencies (fixed audio tone used to generate the CW signal) or varying the audio tone (fixed carrier frequency). This possibility exists due to the rapidity with which the greatest common factor changes with small variations in one or both of the transmit frequencies. The prudent RFI surveyor will not use transmit frequencies yielding maximum possible value of lowest intermodulation order below about 50.

The communications performance analysis, conducted before the survey is even scheduled, can specify the minimum transmit-to-transmit and transmit-to-receive frequency separations allowable. No RFI survey test transmission frequency pair may violate the transmit-to-transmit frequency limit. This requirement does not impose a harsh restriction on the test transmission frequency choice, but it is an influence which cannot be ignored.

IX CHECKS REQUIRED FOR RELIABLE SURVEY DATA

The people conducting an RFI survey cannot afford to assume anything concerning the details of the procedure. Too much is riding on the survey results for any suppositions to be allowed to control the worth of the data.

The test transmitters must be connected to the correct antennas with the CW signals actually on the test frequencies chosen. Both transmitters must be operating simultaneously during the monitoring of intermodulation signals. Any doubt about the accuracy of a monitoring receiver's frequency calibration must be removed before the survey is attempted. To assure reliability of intermodulation signal level data, noise figure and effective bandwidth of the monitoring receiver must be known. (As an example, a receiver with a noise figure of 17 dB above thermal and 3kHz bandwidth establishes a -122 dBm receiver noise power reference for comparison with the intermodulation signal power.)

Such a hard-nosed attitude may appear to be ridiculous and unjustifiable. However, bitter experiences where much time was wasted or wrong conclusions were made about intermodulation interference conditions have emphasized the wisdom of knowing rather than guessing. It is much better to take a small amount of reliable data during a survey than to amass pages of data which are nonsense or questionable because key survey factors were taken for granted.

The calculations now available have a number of built-in crosschecks. Therefore, the results from manipulating the numbers can be relied on. Also, the use of an electronic calculator further decreases the probability of error. But, as in the computer world, "Garbage in gives garbage out."

X NEED FOR BROADBAND ANTENNA EXCITATION

The goal of the RFI survey is to determine indirectly the probability of intermodulation interference and to locate the worst sources, if the probability is high. RFI sources can be classified as "worst" because of the strong currents flowing in them at transmit frequencies. It is then that the highest order intermodulation signals will be generated at significantly strong levels. If a source exists in the transmit feed system, antenna, or immediate vicinity of the antenna, it will be driven by a strong current at the transmission frequency.

A broadband transmit antenna, covering a 3 to 1 frequency range and fed by a number of transmitters via a multicoupler, provides high level excitation of an RFI source at more than one transmission frequency. When the two RFI survey test transmissions are radiated by a broadband antenna, conditions are optimum for any possible RFI sources in or near that antenna system to cause the observation of appreciably strong intermodulation signals at high orders by the monitoring receiver.

During the survey each of the broadband transmit antennas on the ship must be fed by a pair of simultaneous test transmissions to assure a comprehensive investigation. Of course, while transmissions are made on any one broadband antenna the intermodulation signals are monitored by connecting the receiver to each available receive antenna in turn.

XI NEED FOR USE OF ALL RECEIVE ANTENNAS

The basic process of the RFI survey is to determine the highest intermodulation signal order detectable by one of the ship's communications receivers serving temporarily as an RFI monitor. On some ships there are several receiving antennas available for the HF band. It is important that the survey include all possible combinations of monitoring receiver and antenna to make sure the survey is comprehensive.

While observing changes in intermodulation signal level at a fixed frequency and given order, the investigator should not be surprised if there is considerable level change as the different antennas are sampled. This variability can be exploited to improve the value of the survey. With a receiver/antenna combination yielding the highest level, the investigator should proceed with the monitoring at higher intermodulation orders. Conversely, with a receiver/antenna combination where the level is lowest, or even undetectable, the procedure should be to monitor lower intermodulation orders. From the results of these checks valuable decisions can be made about the general location of a worst source before any locating action is taken.

The main reason for a wide range of signal levels as receiving antennas are changed is the difference in coupling or path loss from the intermodulation signal sources and the antennas. In general, the range of levels will be greater as the frequency of the monitored signal increases.

XII THE SPECIAL TUNED WHIP ANTENNA CASE

On most ships there is a group of tunable HF transmit antennas. These are usually 35-foot whips fed by tunable couplers. A whip coupler both resonates the whip at the transmit frequency and provides an impedance at its input terminals which causes a low VSWR with respect to 50 ohms. Thus, the whip sees a conjugate equivalent source impedance, and the transmitter feeding the whip/coupler combination sees an acceptable load. Unfortunately, all of the presently used whip antenna couplers have a number of latent RFI sources built-in.....ferromagnetic connectors, ferrite coil cores, sliding contacts, and switch contacts. Equally unfortunate is the relative lack of selectivity when the coupler—a single-stage tunable impedance transformer—is compared to a two-stage transmit multicoupler.

The RFI survey can be considered as divided into two phases—broadband only and combined broadband and narrowband. During the broadband phase all whip antennas are disconnected from their couplers. CW test transmissions are fed into broadband antennas through multicouplers.

Once the broadband survey phase is complete—even to locating worst RFI sources—the tuned whips are fed one at a time by one CW test transmission with the other transmission from a nearby broadband antenna. (Inactive whips remain unconnected to the tuned couplers.) In this manner controlled circumstances are set up to avoid the confusion from the simultaneous generation of intermodulation signals in whip couplers and in sources not a part of the transmit system.

This procedure has become necessary because several field trips have been scrubbed due to the severity of interference from whip couplers used to excite possible topside sources.

XIII TWO WAYS TO FIND THE HIGHEST SIGNIFICANT INTERMODULATION SIGNAL ORDER, PLUS OPTIONS

The most important parts of the RFI survey procedure are the choices of CW test transmission frequencies and monitored intermodulation frequencies. When first confronted with the detailed calculations necessary to establish a firm foundation for the survey, one is liable to feel concern about the apparent mathematical complexity. But all the calculations are actually simple arithmetic, and the use of an electronic calculator is a great help in getting the desired results quickly and accurately. Much of the original concern about the survey calculations melts away once the investigator becomes familiar with the procedure by making a number of practice calculations. In fact, the quite fascinating interrelationships of the numbers make a sort of game or puzzle of the calculations. As a result, the investigator may actually enjoy setting up the survey fundamentals.

The crucial first step is the calculation of the greatest common factor between the two test transmission frequencies. This is done by a sequence of divisions until the final remainder is zero. The process is most clearly described by an example. Suppose the two frequencies are 3304 and 4711 kHz.

$$(a) \begin{array}{r} 3304 \overline{) 4711} \\ \underline{3304} \\ 1407 \end{array}$$

$$(e) \begin{array}{r} 63 \overline{) 427} \\ \underline{378} \\ 49 \end{array}$$

$$(b) \begin{array}{r} 1407 \overline{) 3304} \\ \underline{2814} \\ 490 \end{array}$$

$$(f) \begin{array}{r} 49 \overline{) 63} \\ \underline{49} \\ 14 \end{array}$$

$$(c) \begin{array}{r} 490 \overline{) 1407} \\ \underline{980} \\ 427 \end{array}$$

$$(g) \begin{array}{r} 14 \overline{) 49} \\ \underline{42} \\ 7 \end{array}$$

$$(d) \begin{array}{r} 427 \overline{) 490} \\ \underline{427} \\ 63 \end{array}$$

$$(h) \begin{array}{r} 7 \overline{) 14} \\ \underline{14} \\ \text{zero} \end{array}$$

The zero remainder in step (h) proves that the remainder in step (g) is the greatest common factor. Across the whole frequency spectrum only those frequencies which are multiples of 7 kHz are qualified intermodulation signal frequencies caused by the simultaneous transmissions at 3304 and 4711 kHz. With the 3 kHz IF bandwidth of the usual monitoring receiver it is easy to distinguish between adjacent intermodulation signals separated by 7 kHz. If the greatest common factor were

2 or 1 kHz, it would be possible for two or three adjacent intermods to be within the receiver bandwidth. Under some circumstances this situation could lead to confusion about both signal level and specific intermodulation signal frequency and order.

The greatest common factor can be used to find the maximum value possible for the lowest observed intermodulation signal order. Division of the sum of the two test transmission frequencies by twice the greatest common factor, ignoring the remainder of ½ if it occurs, gives this important number.

$$3304 + 4711 = 8015$$

$$2 \times 7 = 14$$

$$14 \overline{) 8015} = 572.5$$

No intermodulation signal over the frequency range from 7 kHz to the 572nd harmonic of the lower test transmission frequency, 1889.888 MHz, will have a lowest order greater than 572.....

$572 \times 3304 = 1889888$. (The reference to "lowest order" is necessary, because on any qualified intermodulation frequency there are a number of intermodulation signals of different orders. But the observed signal level at a given intermodulation frequency will be controlled by that intermod having the lowest order. By another simple application of the greatest common factor it is possible to predict the orders of all intermods superimposed on a single intermodulation frequency, but the information is not important enough to be included in this discussion.)

There are two options available to the RFI investigator for finding the intermodulation signals to be monitored. He can calculate the frequencies where the lowest order is the one he has chosen to investigate, or he can sweep the spectrum until he finds the weakest, but still significantly strong, intermodulation signal and then calculate its lowest order.

The first option has the advantage of the simplest calculation. It does, however, require the investigator to guess what order may be the highest one detectable. Once the frequencies of that order are monitored, a subjective decision must be made whether a lower order should be checked (because the intermods of the chosen order are not strong enough to be observed) or a higher order will be a more valuable indication of RFI potential (because the original order choice gave intermods of unexpectedly high signal level.)

Intermodulation signals generated by two simultaneous transmissions can be divided into three categories. Type I is where the factor multiplying the lower transmit frequency is positive and the factor multiplying the higher transmit frequency is negative, as in this 17th order, $(+11 \times 3304) + (-6 \times 4711)$, at the intermod frequency 8078 kHz. Type II is where the factor multiplying the

higher transmit frequency is positive and the factor multiplying the lower transmit frequency is negative, as in this 12th order, $(-5 \times 3304) + (+7 \times 4711)$, at the intermod frequency 16457 kHz. Type III has both factors positive, as in this 7th order, $(+4 \times 3304) + (+3 \times 4711)$, at the intermod frequency 27349 kHz. (Type III intermods occur only between harmonics of the two transmit frequencies.)

There is a very simple method for calculating all possible intermodulation signal frequencies for each type, once the decision is made for a specific intermod order. For example, suppose the investigator wishes to monitor a number of 17th order intermodulation signals where they occur in the HF band.

Type I $17 \times 3304 = 56168$, the 17th harmonic of the lower transmit frequency establishes the limit of all 17th order Type I intermod frequencies. Although 56168 is far out of the HF spectrum, it can be used to quickly calculate all the other Type I intermods possible by repeatedly subtracting the sum of the transmit frequencies, $3304 + 4711 = 8015$.

$56168 - 8015 = 48153$	$24108 - 8015 = \underline{16093}$
$48153 - 8015 = 40138$	$16093 - 8015 = \underline{8078}$
$40138 - 8015 = 32123$	$8078 - 8015 = 63$
$32123 - 8015 = \underline{24108}$	

In the HF band Type I, 17th order intermodulation signals can be monitored at 8078, 16093, and 24108 kHz.

Type II $17 \times 4711 = 80087$, the 17th harmonic of the higher transmit frequency is the Type II limit. Again, the intermods in the HF band are found from repeated subtraction of 8015.

$80087 - 8015 = 72072$	$40012 - 8015 = 31997$
$72072 - 8015 = 64057$	$31997 - 8015 = \underline{23982}$
$64057 - 8015 = 56042$	$23982 - 8015 = \underline{15967}$
$56042 - 8015 = 48027$	$15967 - 8015 = \underline{7952}$
$48027 - 8015 = 40012$	

In the HF band Type II, 17th order intermodulation signals can be monitored at 7952, 15967, and 23982 kHz.

Type III Although in this example all the Type III, 17th order intermods are well above the 30000 kHz upper limit of the HF band, they will be calculated here to show the procedure. These frequencies can be found by two methods—repeated addition of the difference between the two

transmit frequencies, $4711 - 3304 = 1407$, above the 17th harmonic of the lower transmit frequency; repeated subtraction of the transmit frequencies' difference below the 17th harmonic of the higher transmit frequency.

$56168 + 1407 = 57575$	$67424 + 1407 = 68831$
$57575 + 1407 = 58982$	$68831 + 1407 = 70238$
$58982 + 1407 = 60389$	$70238 + 1407 = 71645$
$60389 + 1407 = 61796$	$71645 + 1407 = 73052$
$61796 + 1407 = 63203$	$73052 + 1407 = 74459$
$63203 + 1407 = 64610$	$74459 + 1407 = 75866$
$64610 + 1407 = 66017$	$75866 + 1407 = 77273$
$66017 + 1407 = 67424$	$77273 + 1407 = 78680$
$(78680 + 1407 = 80087 = 17 \times 4711, \text{crosscheck})$	

$80087 - 1407 = 78680$	$68831 - 1407 = 67424$
$78680 - 1407 = 77273$	$67424 - 1407 = 66017$
$77273 - 1407 = 75866$	$66017 - 1407 = 64610$
$75866 - 1407 = 74459$	$64610 - 1407 = 63203$
$74459 - 1407 = 73052$	$63203 - 1407 = 61796$
$73052 - 1407 = 71645$	$61796 - 1407 = 60389$
$71645 - 1407 = 70238$	$60389 - 1407 = 58982$
$70238 - 1407 = 68831$	$58982 - 1407 = 57575$
$(57575 - 1407 = 56168 = 17 \times 3304, \text{crosscheck})$	

(Three interesting items: (1) there are always twice the order total possible intermods of all three types, including the harmonics; (2) there are always one less than the order Type III intermods; (3) there are always one less than the order Type I plus Type II intermods, but the division between these two types is impossible to predict before calculations are completed.)

Of course, it is not necessary to monitor the levels at all intermodulation frequencies where a specific order occurs. The calculations just described generate a pool of accurately predicted frequencies from which samples may be taken.

The second option deals with only one intermodulation signal frequency at a time. The arithmetic is a bit more involved, and an accurate knowledge of the intermod frequency is demanded. (The use of a frequency counter isn't mandatory, since any intermod frequency is qualified by being

a multiple of the greatest common factor. An estimate of frequency can be modified to give the nearest GCF multiple.)

The quotient in each step of the repetitive division sequence can be used in a cumulative process to arrive at an important number at the step where the greatest common factor appears. Refer back to the steps in the example where the two CW test frequencies are 3304 and 4711 kHz. Note that the greatest common factor, 7, can be divided into the remainders resulting from each step. This means these remainders are qualified intermodulation frequencies themselves. The simplest way to compute the lowest order at each of these frequencies is the direct calculation of the coefficient for the higher transmit frequency, using that to calculate the coefficient for the lower transmit frequency indirectly.

(a) Quotient = 1; remainder = 1407

In this step the coefficient for the higher transmit frequency is always plus one. Then, because $+1 \times 4711 = +4711$, the product of the lower transmit frequency and its coefficient must be $1407 - 4711 = -3304$. Then the lower transmit frequency's coefficient must be the quotient of -3304 divided by the frequency 3304, or -1 . So, $1407 = (-1 \times 3304) + (+1 \times 4711)$, 2nd order, Type II.

(b) Quotient = 2; remainder = 490

In this step the coefficient for the higher transmit frequency is always minus the quotient. Then, $-2 \times 4711 = -9422$, and the product of the lower transmit frequency and its coefficient is $490 - (-9422) = +9912$. The lower transmit frequency coefficient is $3304 \sqrt{+9912} = +3$. Hence, $490 = (+3 \times 3304) + (-2 \times 4711)$, 5th order, Type I.

(c) Quotient = 2; remainder = 427

In this and all the following steps the coefficient for the higher transmit frequency is built in this way: the coefficient from two steps previously (here $+1$ from step (a)) is combined with minus the product of the coefficient from the immediately preceding step (here -2 from step (b)) and the quotient in the step being considered. The present combination is $+1 - (-2 \times 2) = +5$, higher frequency coefficient. The rest of the process is as before.

$$+5 \times 4711 = +23555$$

$$427 - 23555 = -23128$$

$$3304 \sqrt{-23128} = -7, \text{ lower frequency coefficient}$$

$$427 = (-7 \times 3304) + (+5 \times 4711), 12\text{th order, Type II}$$

(d) Quotient = 1; remainder = 63

Coefficient from step (b) = -2

Coefficient from step (c) = +5

Combination is $-2 - (+5 \times 1) = -7$, higher frequency coefficient.

$$-7 \times 4711 = -32977$$

$$63 - (-32977) = +33040$$

$$\underline{3304} \sqrt{+33040} = +10, \text{ lower frequency coefficient}$$

$$63 = (\underline{+10} \times 3304) + (\underline{-7} \times 4711), \text{ 17th order, Type I}$$

(e) Quotient = 6; remainder = 49

Coefficient from step (c) = +5

Coefficient from step (d) = -7

Combination is $+5 - (-7 \times 6) = +47$, higher frequency coefficient

$$+47 \times 4711 = +221417$$

$$49 - 221417 = -221368$$

$$\underline{3304} \sqrt{-221368} = -67, \text{ lower frequency coefficient}$$

$$49 = (\underline{-67} \times 3304) + (\underline{+47} \times 4711), \text{ 114th order, Type II}$$

(f) Quotient = 1; remainder = 14

Coefficient from step (d) = -7

Coefficient from step (e) = +47

Combination is $-7 - (+47 \times 1) = -54$, higher frequency coefficient

$$-54 \times 4711 = -254394$$

$$14 - (-254394) = +254408$$

$$\underline{3304} \sqrt{+254408} = +77, \text{ lower frequency coefficient}$$

$$14 = (\underline{+77} \times 3304) + (\underline{-54} \times 4711), \text{ 131st order, Type I}$$

(g) Quotient = 3; remainder = 7, the greatest common factor

Coefficient from step (e) = +47

Coefficient from step (f) = -54

Combination is $+47 - (-54 \times 3) = +209$, higher frequency coefficient

$$+209 \times 4711 = +984599$$

$$7 - 984599 = -984592$$

$$\underline{3304} \sqrt{-984592} = -298, \text{ lower frequency coefficient}$$

$$7 = (\underline{-298} \times 3304) + (\underline{+209} \times 4711), \text{ 507th order, Type II}$$

Before accepting as correct the coefficient for the higher transmit frequency in the step where the remainder is the greatest common factor, it is worthwhile taking advantage of a crosscheck available in the next and final step. If the lower transmit frequency is divided by the greatest common factor, the quotient is the value for the higher frequency coefficient in the final step; $7 \sqrt{3304} = 472$. Similarly, the value of the lower frequency coefficient in the final step is $7 \sqrt{4711} = 673$.

(h) Quotient = 2; remainder = zero

Coefficient from step (f) = -54

Coefficient from step (g) = +209

Combination is $-54 - (+209 \times 2) = -472$, higher frequency coefficient

and crosscheck

$$-472 \times 4711 = -2223592$$

$$\text{zero} - (-2223592) = +2223592$$

$$\underline{3304} \sqrt{+2223592} = +673, \text{ lower frequency coefficient}$$

and crosscheck

(In all the above calculations, time was spent in each step calculating not only the coefficient for the higher transmit frequency but also the lower frequency coefficient, the lowest order intermod on the remainder frequency, and the intermod type. Justification for the items other than higher transmit frequency coefficients was the educational value. But, in the interest of speed, only the higher frequency coefficient should be calculated for each step until the greatest common factor step is reached. Only then is it necessary to calculate the lower transmit frequency coefficient also.)

Now that the correct coefficients for both transmit frequencies at the greatest common factor intermodulation signal frequency have been found and checked, they can be used to find the lowest order on any qualified intermodulation signal frequency. One of these interference frequencies calculated under the examples for the first option was 16093 kHz. The lowest order was 17th; it was a Type I. This intermodulation frequency will be the example to complete the explanation of the second option calculations.

The steps for calculating the lowest order are:

Coefficient for the lower transmit frequency

(1) Divide the intermodulation frequency, 16093, by the greatest common factor, 7.

$$\underline{7} \sqrt{16093} = 2299$$

(2) Multiply by the coefficient for the lower transmit frequency where the intermodulation frequency is the greatest common factor, -298. $2299 \times (-298) = -685102$

(3) Divide by the coefficient for the lower transmit frequency where the intermodulation frequency is zero, +673.

$$+673 \overline{) -685102} = -1017.982169, \text{ or } -1017 \cdot 0.982169.$$

But the remainder in this division must be less than 0.5000, so the quotient is increased from -1017 to -1018 for a positive remainder of only +0.017831.

(4) Multiply -1018 x (+673) = -685114

(5) Subtract from -685102, step 2. $-685102 - (-685114) = +12$

THE COEFFICIENT FOR THE LOWER TRANSMIT FREQUENCY AT THE INTERMODULATION SIGNAL FREQUENCY IS +12.

Coefficient for the higher transmit frequency

(1) Multiply the quotient from the previous step 1, 2299, by the coefficient for the higher transmit frequency where the intermodulation frequency is the greatest common factor, +209. $2299 \times (+209) = +480491$

(2) Multiply the quotient derived in the previous step 3, -1018, by the coefficient for the higher transmit frequency where the intermodulation frequency is zero, -472.
 $-1018 \times (-472) = +480496$

(3) Subtract from +480491, step 1. $+480491 - 480496 = -5$

THE COEFFICIENT FOR THE HIGHER TRANSMIT FREQUENCY AT THE INTERMODULATION SIGNAL FREQUENCY IS -5.

(A shorter, more direct method of calculating the coefficient for the higher transmit frequency can be used. It is dependent on the result of the lower transmit frequency calculation.)

(1) Multiply the lower transmit frequency, 3304, by its coefficient, +12.

$$3304 \times (+12) = +39648$$

(2) Subtract this product from the intermodulation signal frequency, 16093.

$$16093 - (+39648) = -23555$$

(3) Divide this remainder by the higher transmit frequency, 4711. $4711 \overline{) -23555} = -5$

THE COEFFICIENT FOR THE HIGHER TRANSMIT FREQUENCY AT THE INTERMODULATION SIGNAL FREQUENCY IS -5.

The lowest order at the intermodulation frequency, 16093, is the sum of these two coefficients, ignoring signs. $12 + 5 = 17$

There are some occasional peculiar characteristics in the mathematical process of calculating lowest intermodulation orders which make it necessary to check whether any calculated order is truly the lowest order. The check is simple and well worth the short time it takes to test the calculated result. If the coefficient for the lower transmit frequency where the intermodulation frequency is zero, +673, is added to the calculated lower frequency coefficient, then the coefficient for the higher transmit frequency at zero, -472, is added to the calculated higher frequency coefficient. This is half the check. The other half of the check is similar, but involves subtraction. If no smaller coefficient sum than that calculated results, the calculated order is indeed the lowest on the intermodulation frequency being considered. A table clarifies the checkout procedure.

	<u>Low freq. coeff.</u>	<u>High freq. coeff.</u>	<u>Coeff. Sum</u>
"Add" check	+12 + 673 = +685	-5 - 472 = -477	685 + 477 = 1162
ORIGINAL	+12	-5	12 + 5 = 17
"Subt." check	+12 - 673 = -661	-5 + 472 = +467	661 + 467 = 1128

The check is really unnecessary in this example; it is more often needed with a combination of more nearly equal test transmit frequencies and a larger greatest common factor.

Now that the correct coefficients have been found for the lowest intermodulation order, the intermodulation frequency can be written as

$$16093 = (+12 \times 3304) + (-5 \times 4711), 17\text{th order, Type I}$$

The description in words of all the arithmetic steps required to calculate the lowest order intermod on a specific qualified intermodulation signal frequency seems to be as complex as the well-known Abbott and Costello comedy routine, "Who's on first?" But, as the RFI investigator becomes more comfortable with the sequences and develops confidence in the procedure, he will soon appreciate the straight-forward routine of the calculations and how intricate the interrelationships of the various steps are.

The detailed discussion just completed covers the admittedly involved sequence of calculations an RFI investigator must make before and during the survey. However, if a number of desirable elements are made possible concurrently by taking advantage of useful, critical relationships between the transmit test frequencies, the results can be plotted and tabulated. Now, with stringent but practical limitations in the choice of test frequencies, the investigator doesn't have to make calculations for greatest common factor or intermodulation signal lowest order, referring to the tables or a spectrum plot instead.

The most important consideration in developing the "cook book" version of RFI survey calculations for the HF band is forcing the lowest order at the frequency equal to the greatest common factor to be as low as possible always. This minimum order is the 3rd. (There are two 3rd orders possible.....in the Type I the higher transmit frequency is subtracted from 2 times the lower transmit frequency; in the Type II twice the lower transmit frequency is subtracted from the higher transmit frequency.) When the smallest intermodulation signal frequency is always a 3rd order, the orders of all adjacent intermodulation signals across the spectrum differ by only 3 or less, a great advantage. Furthermore, the pattern of an intermodulation signal orders plot versus frequency, normalized with respect to the greatest common factor, is very orderly and easily read.

Another important consideration is putting a limit on the maximum possible value for order to force a larger number of qualified intermodulation signal frequencies to give data about the RFI potential of the ship being surveyed. A good choice for the limit is the 50th order. (The maximum possible order for the case where the smallest intermodulation frequency is a Type I 3rd order is 49, not 50.) It is now possible for the RFI investigator to more easily find the highest intermodulation order with a significant signal strength by monitoring a smaller frequency range.

The simultaneous demands for 3rd order at the smallest intermodulation signal frequency and the 50th order limitation on the maximum possible put a very rigid control on the choice of transmit test frequency pairs. In the Type I case the lower transmit frequency must be 33 times the greatest common factor, and the higher transmit frequency coefficient is 65. In the Type II case the lower transmit frequency is again 33 times the greatest common factor, but now the higher transmit frequency coefficient becomes 67. In the Type I case the greatest common factor is a minimum of 61 kHz with transmit frequency pair 2013 and 3965 kHz, increasing to a maximum of 461 kHz with 15213 and 29965 kHz. Although the Type II case repeats the minimum greatest common factor of 61 kHz with 2013 and 4087 kHz transmit frequencies, the maximum is only 447 kHz with a 14751 and 29949 kHz combination. As a consequence, the number of possible intermodulation signal frequencies between 2 and 30 MHz drops from slightly more than 450 with the minimum intermodulation signal separation to about 60 at the maximum separation. A table of all possible test transmission frequency pairs and associated greatest common factors for both Type I and Type II cases has been prepared.

Another valuable tool for the investigator can be devised from the specific transmit frequency relationships. By plotting all intermodulation signal frequencies, normalized by division of the greatest common factor, against the lowest orders from D.C. to beyond 30 MHz, a very useful

**TEST TRANSMISSION FREQUENCY PAIRS AND
ASSOCIATED GREATEST COMMON FACTORS**

QC = 3rd order, Type I; QMAX = 49; T1 = 33C; T2 = 65C

GCF kHz	T1 kHz	T2 kHz	GCF kHz	T1 kHz	T2 kHz
61	2013	3965	106	3498	6890
62	2046	4030	107	3531	6955
63	2079	4095	108	3564	7020
64	2112	4160	109	3597	7085
65	2145	4225	110	3630	7150
66	2178	4290	111	3663	7215
67	2211	4355	112	3696	7280
68	2244	4420	113	3729	7345
69	2277	4485	114	3762	7410
70	2310	4550	115	3795	7475
71	2343	4615	116	3828	7540
72	2376	4680	117	3861	7605
73	2409	4745	118	3894	7670
74	2442	4810	119	3927	7735
75	2475	4875	120	3960	7800
76	2508	4940	121	3993	7865
77	2541	5005	122	4026	7930
78	2574	5070	123	4059	7995
79	2607	5135	124	4092	8060
80	2640	5200	125	4125	8125
81	2673	5265	126	4158	8190
82	2706	5330	127	4191	8255
83	2739	5395	128	4224	8320
84	2772	5460	129	4257	8385
85	2805	5525	130	4290	8450
86	2838	5590	131	4323	8515
87	2871	5655	132	4356	8580
88	2904	5720	133	4389	8645
89	2937	5785	134	4422	8710
90	2970	5850	135	4455	8775
91	3003	5915	136	4488	8840
92	3036	5980	136	4521	8905
93	3069	6045	138	4554	8970
94	3102	6110	139	4587	9035
95	3135	6175	140	4620	9100
96	3168	6240	141	4653	9165
97	3201	6305	142	4686	9230
98	3234	6370	143	4719	9295
99	3267	6435	144	4752	9360
100	3300	6500	145	4785	9425
101	3333	6565	146	4818	9490
102	3366	6630	147	4851	9555
103	3399	6695	148	4884	9620
104	3432	6760	149	4917	9685
105	3465	6825	150	4450	9750

GCF kHz	T1 kHz	T2 kHz	GCF kHz	T1 kHz	T2 kHz
151	4983	9815	204	6732	13260
152	5016	9880	205	6765	13325
153	5049	9945	206	6798	13390
154	5082	10010	207	6831	13455
155	5115	10075	208	6864	13520
156	5148	10140	209	6897	13585
157	5181	10205	210	6930	13650
158	5214	10270	211	6963	13715
159	5247	10335	212	6996	13780
160	5280	10400	213	7029	13845
161	5313	10465	214	7062	13910
162	5346	10530	215	7095	13975
163	5379	10595	216	7128	14040
164	5412	10660	217	7161	14105
165	5445	10725	218	7194	14170
166	5478	10790	219	7227	14235
167	5511	10855	220	7260	14300
168	5544	10920	221	7293	14365
169	5577	10985	222	7326	14430
170	5610	11050	223	7359	14495
171	5643	11115	224	7392	14560
172	5676	11180	225	7425	14625
173	5709	11245	226	7458	14690
174	5742	11310	227	7491	14755
175	5775	11375	228	7524	14820
176	5808	11440	229	7557	14885
177	5841	11505	230	7590	14950
178	5874	11570	231	7623	15015
179	5907	11635	232	7656	15080
180	5940	11700	233	7689	15145
181	5973	11765	234	7722	15210
182	6006	11830	235	7755	15275
183	6039	11895	236	7788	15340
184	6072	11960	237	7821	15405
185	6105	12025	238	7854	15470
186	6138	12090	239	7887	15535
187	6171	12155	240	7920	15600
188	6204	12220	241	7953	15665
189	6237	12285	242	7986	15730
190	6270	12350	243	8019	15795
191	6303	12415	244	8052	15860
192	6336	12480	245	8085	15925
193	6369	12545	246	8118	15990
194	6402	12610	247	8151	16055
195	6435	12675	248	8184	16120
196	6468	12740	249	8217	16185
197	6501	12805	250	8250	16250
198	6534	12870	251	8283	16315
199	6567	12935	252	8316	16380
200	6600	13000	253	8349	16445
201	6633	13065	254	8382	16510
202	6666	13130	255	8415	16575
203	6699	13195	256	8448	16640

GCF kHz	T1 kHz	T2 kHz	GCF kHz	T1 kHz	T2 kHz
257	8481	16705	309	10197	20085
258	8514	16770	310	10230	20150
259	8547	16835	311	10263	20215
260	8580	16900	312	10296	20280
261	8613	16965	313	10329	20345
262	8646	17030	314	10362	20410
263	8679	17095	315	10395	20475
264	8712	17160	316	10428	20540
265	8745	17225	317	10461	20650
266	8778	17290	318	10494	20670
267	8811	17355	319	10527	20735
268	8844	17420	320	10560	20800
269	8877	17485	321	10593	20865
270	8910	17550	322	10626	20930
271	8943	17615	323	10659	20995
272	8976	17680	324	10692	21060
273	9009	17745	325	10725	21125
274	9042	17810	326	10758	21190
275	9075	17875	327	10791	21255
276	9108	17940	328	10824	21320
277	9141	18005	329	10857	21385
278	9174	18070	330	10890	21450
279	9207	18135	331	10923	21515
280	9240	18200	332	10956	21580
281	9273	18265	333	10989	21645
282	9306	18330	334	11022	21710
283	9339	18395	335	11055	21775
284	9372	18460	336	11088	21840
285	9405	18525	337	11121	21905
286	9438	18590	338	11154	21970
287	9471	18655	339	11187	22035
288	9504	18720	340	11220	22100
289	9537	18785	341	11253	22165
290	9570	18850	342	11286	22230
291	9603	18915	343	11319	22295
292	9636	18980	344	11352	22360
293	9669	19045	345	11385	22425
294	9702	19110	346	11418	22490
295	9735	19175	347	11451	22555
296	9768	19240	348	11484	22620
297	9801	19305	349	11517	22685
298	9834	19370	350	11550	22750
299	9867	19435	351	11583	22815
300	9900	19500	352	11616	22880
301	9933	19565	353	11649	22945
302	9966	19630	354	11682	23010
303	9999	19695	355	11715	23075
304	10032	19760	356	11748	23140
305	10065	19825	357	11781	23205
306	10098	19890	358	11814	23270
307	10131	19955	359	11847	23335
308	10164	20020			

GCF kHz	T1 kHz	T2 kHz	GCF kHz	T1 kHz	T2 kHz
360	11880	23400	411	13563	26715
361	11913	23465	412	13596	26780
362	11946	23530	413	13629	26845
363	11979	23595	414	13662	26910
364	12012	23660	415	13695	26975
365	12045	23725	416	13728	27040
366	12078	23790	417	13761	27105
367	12111	23855	418	13794	27170
368	12144	23920	419	13827	27235
369	12177	23985	420	13860	27300
370	12210	24050	421	13893	27365
371	12243	24115	422	13926	27430
372	12276	24180	423	13959	27495
373	12309	24245	424	13992	27560
374	12342	24310	425	14025	27625
375	12375	24375	426	14058	27690
376	12408	24440	427	14091	27755
377	12441	24505	428	14124	27820
378	12474	24570	429	14157	27885
379	12507	24635	430	14190	27950
380	12540	24700	431	14223	28015
381	12573	24765	432	14256	28080
382	12606	24830	433	14289	28145
383	12639	24895	434	14322	28210
384	12672	24960	435	14355	28275
385	12705	25025	436	14388	28340
386	12738	25090	437	14421	28405
387	12771	25155	438	14454	28470
388	12804	25220	439	14487	28535
389	12837	25285	440	14520	28600
390	12870	25350	441	14553	28665
391	12903	25415	442	14586	28730
392	12936	25480	443	14619	28795
393	12969	25545	444	14652	28860
394	13002	25610	445	14685	28925
395	13035	25675	446	14718	28990
396	13068	25740	447	14751	29055
397	13101	25805	448	14784	29120
398	13134	25870	449	14817	29185
399	13167	25935	450	14850	29250
400	13200	26000	451	14883	29315
401	13233	26065	452	14916	29380
402	13266	26130	453	14949	29445
403	13299	26195	454	14982	29510
404	13332	26260	455	15015	29575
405	13365	26325	456	15048	29640
406	13398	26390	457	15081	29705
407	13431	26455	458	15114	29770
408	13464	26520	459	15147	29835
409	13497	26585	460	15180	29900
410	13530	26650	461	15213	29965

**TEST TRANSMISSION FREQUENCY PAIRS AND
ASSOCIATED GREATEST COMMON FACTORS**

QC = 3rd, Type II, QMAX = 50, T1 = 33C, T2 = 67C, A2 = 33

GCF kHz	T1 kHz	T2 kHz	GCF kHz	T1 kHz	T2 kHz
61	2013	4087	106	3498	7102
62	2046	4154	107	3531	7169
63	2079	4221	108	3564	7236
64	2112	4288	109	3597	7303
65	2145	4355	110	3630	7370
66	2178	4422	111	3663	7437
67	2211	4489	112	3696	7504
68	2244	4556	113	3729	7571
69	2277	4623	114	3762	7638
70	2310	4690	115	3795	7705
71	2343	4757	116	3828	7772
72	2376	4824	117	3861	7839
73	2409	4891	118	3894	7906
74	2442	4958	119	3927	7973
75	2475	5025	120	3960	8040
76	2508	5092	121	3993	8107
77	2541	5159	122	4026	8174
78	2574	5226	123	4059	8241
79	2607	5293	124	4092	8308
80	2640	5360	125	4125	8375
81	2673	5427	126	4258	8442
82	2706	5494	127	4191	8509
83	2739	5561	128	4224	8576
84	2772	5628	129	4257	8643
85	2805	5695	130	4290	8710
86	2838	5762	131	4323	8777
87	2871	5829	132	4356	8844
88	2904	5896	133	4389	8911
89	2937	5963	134	4422	8978
90	2970	6030	135	4455	9045
91	3003	6097	136	4488	9112
92	3036	6164	137	4521	9179
93	3069	6231	138	4554	9246
94	3102	6298	139	4587	9313
95	3135	6365	140	4620	9380
96	3168	6432	141	4653	9447
97	3201	6499	142	4686	9514
98	3234	6566	143	4719	9581
99	3267	6633	144	4752	9648
100	3300	6700	145	4785	9715
101	3333	6767	146	4818	9782
102	3366	6834	147	4851	9849
103	3399	6901	148	4884	9916
104	3432	6968	149	4917	9983
105	3465	7035	150	4950	10050

GCF kHz	T1 kHz	T2 kHz	GCF kHz	T1 kHz	T2 kHz
151	4983	10117	201	6633	13467
152	5016	10184	202	6666	13534
153	5049	10251	203	6699	13601
154	5082	10318	204	6732	13668
155	5115	10385	205	6765	13735
156	5148	10452	206	6798	13802
157	5181	10519	207	6831	13869
158	5214	10586	208	6864	13936
159	5247	10653	209	6897	14003
160	5280	10720	210	6930	14070
161	5313	10787	211	6963	14137
162	5346	10854	212	6996	14204
163	5379	10921	213	7029	14271
164	5412	10988	214	7062	14338
165	5445	11055	215	7095	14405
166	5478	11122	216	7128	14472
167	5511	11189	217	7161	14539
168	5544	11256	218	7194	14606
169	5577	11323	219	7227	14673
170	5610	11390	220	7260	14740
171	5643	11457	221	7293	14807
172	5676	11524	222	7326	14874
173	5709	11591	223	7359	14941
174	5742	11658	224	7392	15008
175	5775	11725	225	7425	15075
176	5808	11792	226	7458	15142
177	5841	11859	227	7491	15209
178	5874	11926	228	7524	15276
179	5907	11993	229	7557	15343
180	5940	12060	230	7590	15410
181	5973	12127	231	7623	15477
182	6006	12194	232	7656	15544
183	6039	12261	233	7689	15611
184	6072	12328	234	7722	15678
185	6105	12395	235	7755	15745
186	6138	12462	236	7788	15812
187	6171	12529	237	7821	15879
188	6204	12596	238	7854	15946
189	6237	12663	239	7887	16013
190	6270	12730	240	7920	16080
191	6303	12797	241	7953	16147
192	6336	12864	242	7986	16214
193	6369	12931	243	8019	16281
194	6402	12998	244	8052	16348
195	6435	13065	245	8085	16415
196	6468	13132	246	8118	16482
197	6501	13199	247	8151	16549
198	6534	13266	248	8184	16616
199	6567	13333	249	8217	16683
200	6600	13400	250	8250	16750

GCF kHz	T1 kHz	T2 kHz	GCF kHz	T1 kHz	T2 kHz
251	8283	16817	301	9933	20167
252	8316	16884	302	9966	20234
253	8349	16951	303	9999	20301
254	8382	17018	304	10032	20368
255	8415	17085	305	10065	20435
256	8448	17152	306	10098	20502
257	8481	17219	307	10131	20569
258	8514	17286	308	10164	20636
259	8547	17353	309	10197	20703
260	8580	17420	310	10230	20770
261	8613	17487	311	10263	20837
262	8646	17554	312	10296	20904
263	8679	17621	313	10329	20971
264	8712	17688	314	10362	21038
265	8745	17755	315	10395	21105
266	8778	17822	316	10428	21172
267	8811	17889	317	10461	21239
268	8844	17956	318	10494	21306
269	8877	18023	319	10527	21373
270	8910	18090	320	10560	21440
271	8943	18157	321	10593	21507
272	8976	18224	322	10626	21574
273	9009	18291	323	10659	21641
274	9042	18358	324	10692	21708
275	9075	18425	325	10725	21775
276	9108	18492	326	10758	21842
277	9141	18559	327	10791	21909
278	9174	18626	328	10824	21976
279	9207	18693	329	10857	22043
280	9240	18760	330	10890	22110
281	9273	18827	331	10923	22177
282	9306	18894	332	10956	22244
283	9339	18961	333	10989	22311
284	9372	19028	334	11022	22378
285	9405	19095	335	11055	22445
286	9438	19162	336	11088	22512
287	9471	19229	337	11121	22579
288	9504	19296	338	11154	22646
289	9537	19363	339	11187	22713
290	9570	19430	340	11220	22780
291	9603	19497	341	11253	22847
292	9636	19564	342	11286	22914
293	9669	19631	343	11319	22981
294	9702	19698	344	11352	23048
295	9735	19765	345	11385	23115
296	9768	19832	346	11418	23182
297	9801	19899	347	11451	23249
298	9834	19966	348	11484	23316
299	9867	20033	349	11517	23383
300	9900	20100	350	11550	23450

GCF kHz	T1 kHz	T2 kHz	GCF kHz	T1 kHz	T2 kHz
351	11583	23517	401	13233	26867
352	11616	23584	402	18266	26934
353	11649	23651	403	13299	27001
354	11682	23718	404	13332	27068
355	11715	23785	405	13365	27135
356	11748	23852	406	13398	27202
357	11781	23919	407	13431	27269
358	11814	23986	408	13464	27336
359	11847	24053	409	13497	27403
360	11880	24120	410	13530	27470
361	11913	24187	411	13563	27537
362	11946	24254	412	13596	27604
363	11979	24321	413	13629	27671
364	12012	24388	414	13662	27738
365	12045	24455	415	13695	27805
366	12078	24522	416	13728	27872
367	12111	24589	417	13761	27939
368	12144	24656	418	13794	28006
369	12177	24723	419	13827	28073
370	12210	24790	420	13860	28140
371	12243	24857	421	13893	28207
372	12276	24924	422	13926	28274
373	12309	24991	423	13959	28341
374	12342	25058	424	13992	28408
375	12375	25125	425	14025	28475
376	12408	25192	426	14058	28542
377	12441	25259	427	14091	28609
378	12474	25326	428	14124	28676
379	12507	25393	429	14157	28743
380	12540	25460	430	14190	28810
381	12573	25527	431	14223	28877
382	12606	25594	432	14256	28944
383	12639	25661	433	14289	29011
384	12672	25728	434	14322	29078
385	12705	25795	435	14355	29145
386	12738	25862	436	14388	29212
387	12771	25929	437	14421	29279
388	12804	25996	438	14454	29346
389	12837	26063	439	14487	29413
390	12870	26130	440	14520	29480
391	12903	26197	441	14553	29547
392	12936	26264	442	14586	29614
393	12969	26331	443	14619	29681
394	13002	26398	444	14652	29748
395	13035	26465	445	14685	29815
396	13068	26532	446	14718	29882
397	13101	26599	447	14751	29949
398	13134	26666			
399	13167	26733			
400	13200	26800			

spectrum analysis is presented. The simulation is enhanced by making the lengths of the lines designating intermodulation signals shorter as the orders increase. Although the actual signal levels would vary in amplitude much more rapidly on an actual spectrum analyzer scope than they do in the plot, the observer is constantly reminded the signal levels do decrease as the intermodulation orders increase. For convenience, both Type I and Type II cases are superimposed on the same chart.

Information can be extracted from the intermodulation spectrum chart and presented in a more convenient tabular form. One table quickly answers the RFI investigator's question, "if I find an intermodulation interference signal on a certain frequency, what is its lowest order?" To enter the table the investigator has only to divide the intermodulation frequency by the greatest common factor for the pair of transmit test frequencies he is using. Lowest orders appear in the table for both Type I and Type II transmit frequency cases. In addition, a table has been constructed for assisting the RFI survey investigator in answering the question, "What intermodulation signal frequencies have a certain lowest order?" The intermodulation frequencies are listed in the normalized form; actual frequencies are found by multiplying these numbers by the greatest common factor for the test transmit frequency pair in use, whether it is Type I or Type II.

The tables of all possible test transmit frequency combinations were derived strictly from application of the mathematics. Which choice is made during a survey must depend on the frequencies available for allocation by the local Communications Area Master Station. There are two great advantages in having a number of frequency pairs assigned permanently for RFI survey work. (The extremely intermittent nature of survey frequency use makes the allocation task a simple one.) The length for tables of transmit frequency pairs collapses to only one or two pages. Also, there would be no uncertainty concerning the availability of test frequencies. A minor point becomes evident if these frequencies were allocated worldwide rather than being different in each Communications Area. Meaningful comparisons of intermodulation signal data from all ships surveyed are then possible.

INTERMODULATION SPECTRUM CHART

SOLID:

T1 = 33C

QMAX = 49 QC = 3, I

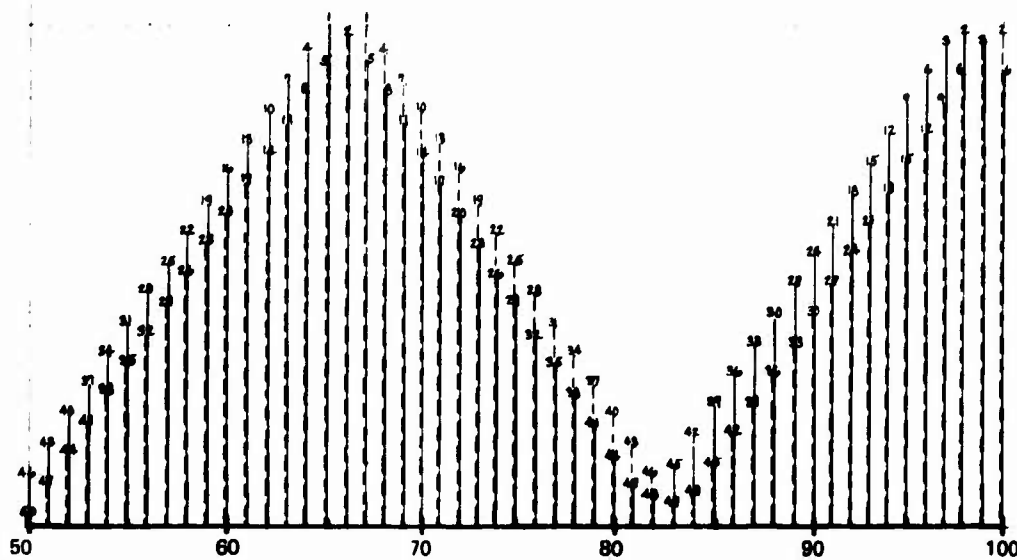
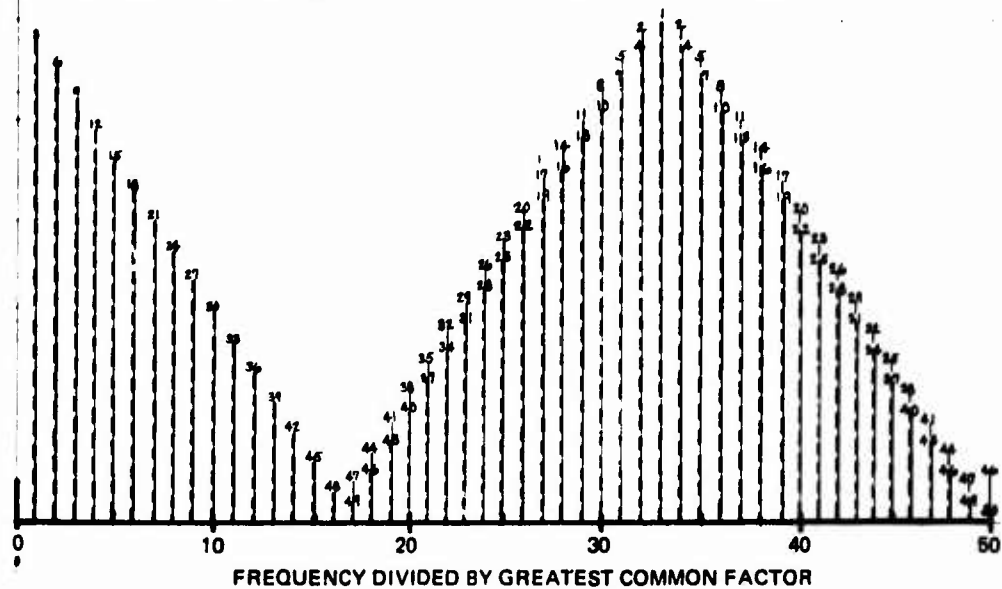
T2 = 65C C = 2T1-T2

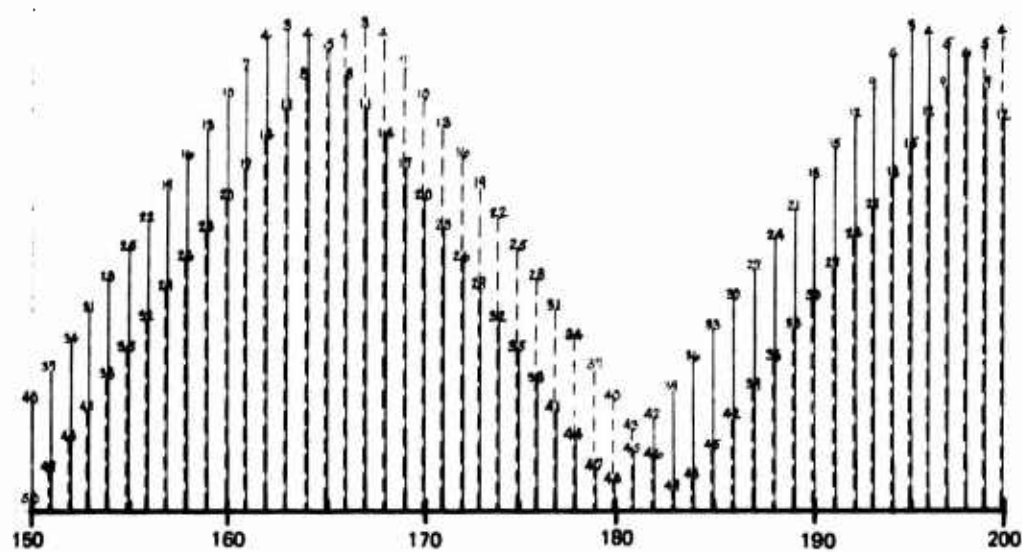
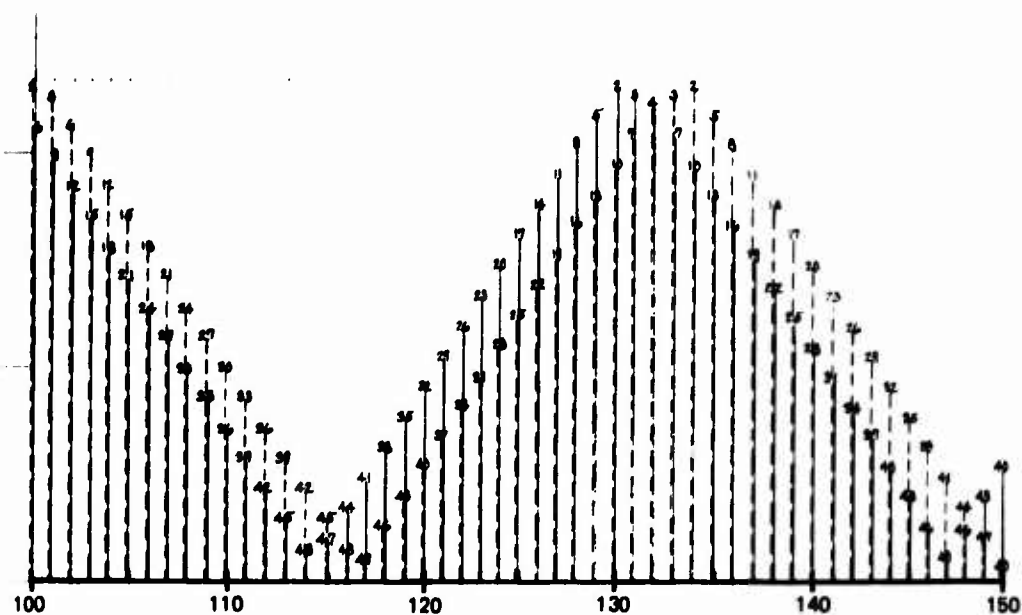
DASHED:

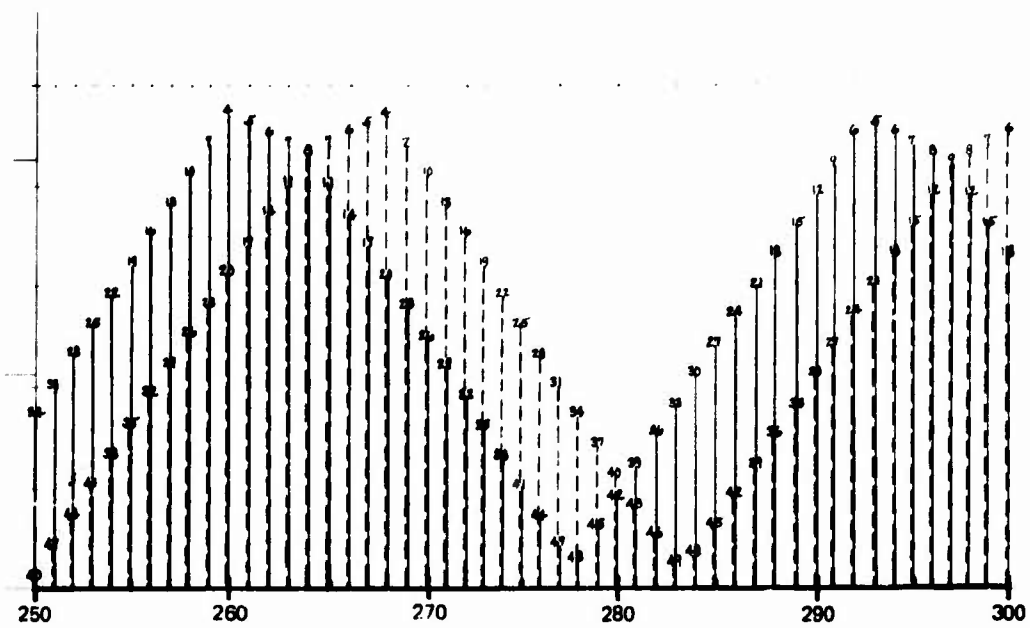
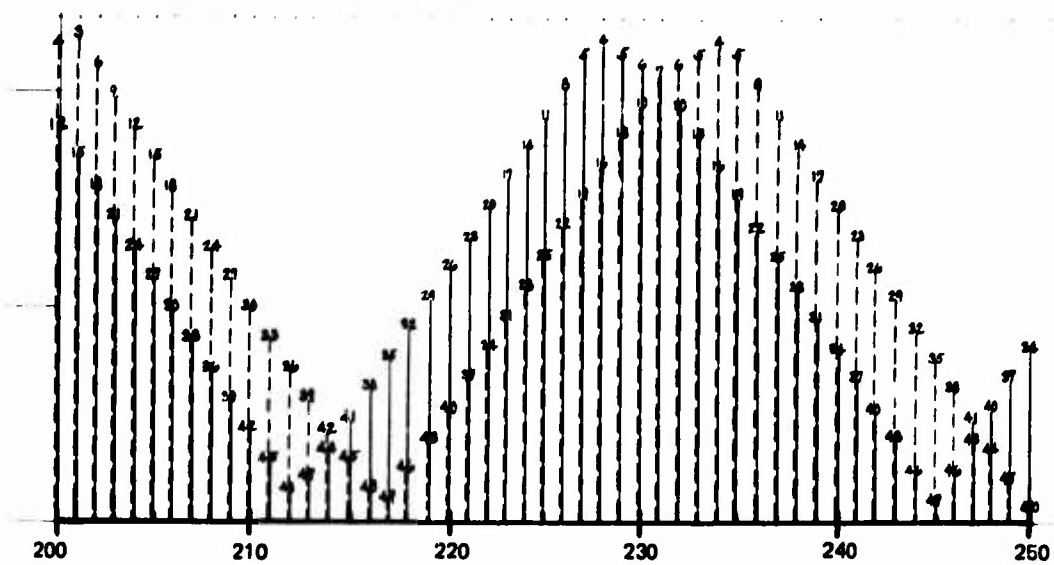
T1 = 33C

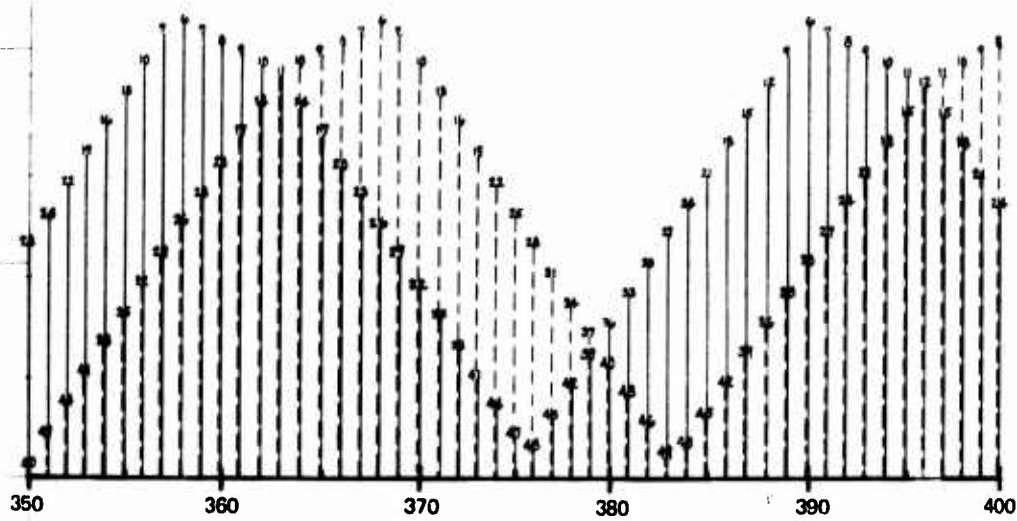
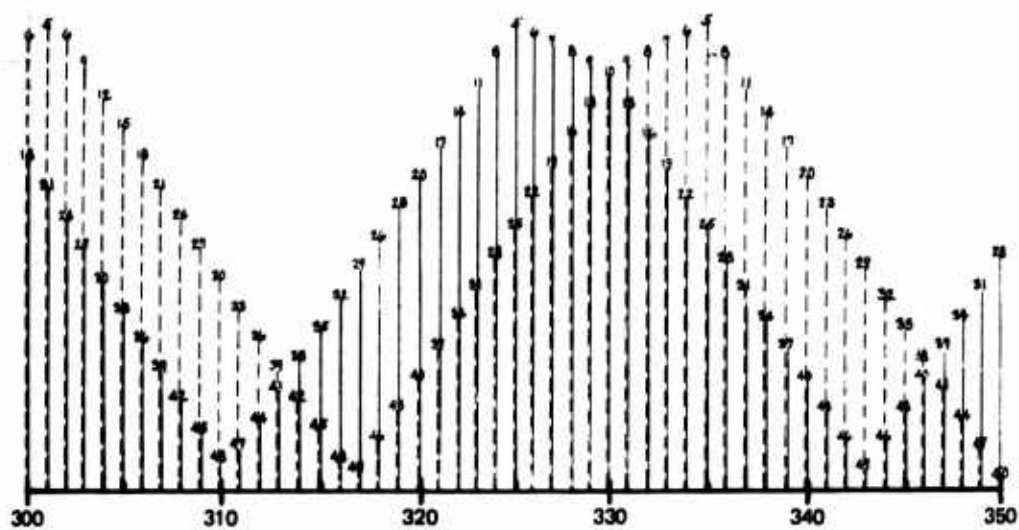
QMAX = 50 QC = 3, II

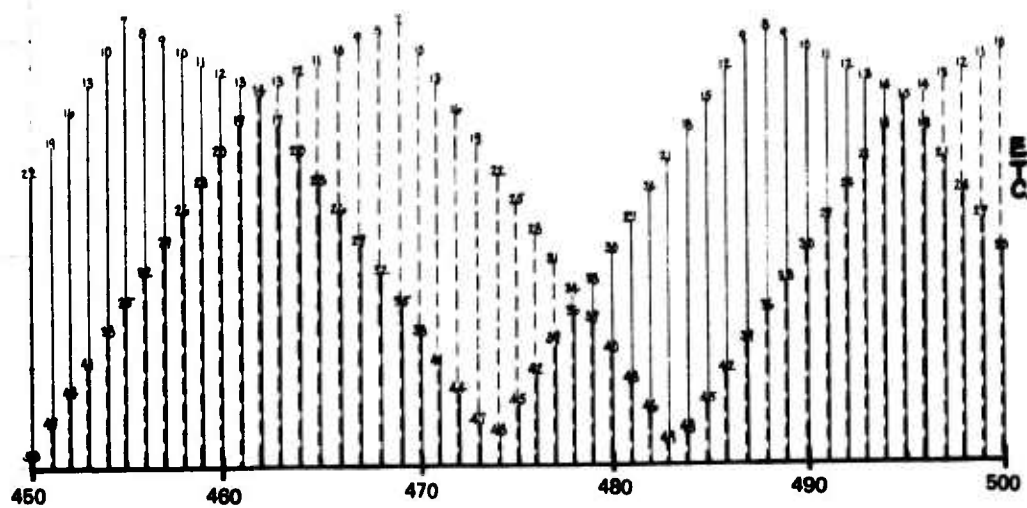
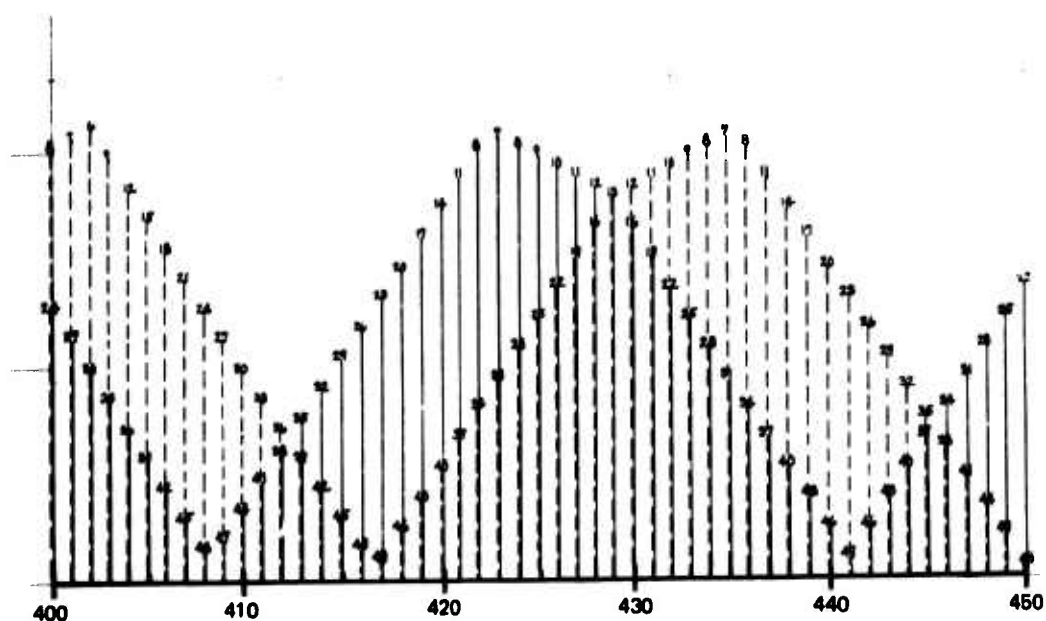
T2 = 67C C = T2-2T1











INTERMOD ORDERS FOR RFI SURVEY MONITORING

FR = intermod frequency monitored with receiver

Type I GCF = $2T_1 - T_2$

Type II GCF = $T_2 - 2T_1$

FR/GCF	I	II	FR/GCF	I	II
1	3	3	47	43	41
2	6	6	48	46	44
3	9	9	49	49	47
4	12	12	50	46	50
5	15	15	51	43	47
6	18	18	52	40	44
7	21	21	53	37	41
8	24	24	54	34	38
9	27	27	55	31	35
10	30	30	56	28	32
11	33	33	57	25	29
12	36	36	58	22	26
13	39	39	59	19	23
14	42	42	60	16	20
15	45	45	61	13	17
16	48	48	62	10	14
17	47	49	63	7	11
18	44	46	64	4	8
19	41	43	65	①	5 (T2 for I)
20	38	40	66	②	② (2T1)
21	35	37	67	5	① (T2 for II)
22	32	34	68	8	4
23	29	31	69	11	7
24	26	28	70	14	10
25	23	25	71	17	13
26	20	22	72	20	16
27	17	19	73	23	19
28	14	16	74	26	22
29	11	13	75	29	25
30	8	10	76	32	28
31	5	7	77	35	31
32	2	4	78	38	34
33	①	① (T1 for both I & II)	79	41	37
34	4	2	80	44	40
35	7	5	81	47	43
36	10	8	82	48	46
37	13	11	83	45	49
38	16	14	84	42	48
39	19	17	85	39	45
40	22	20	86	36	42
41	25	23	87	33	39
42	28	26	88	30	36
43	31	29	89	27	33
44	34	32	90	24	30
45	37	35	91	21	27
46	40	38	92	18	24

FR/GCF	I	II		FR/GCR	I	II
93	15	21		144	40	32
94	12	18		145	43	35
95	9	15		146	46	38
96	6	12		147	49	41
97	3	9		148	46	44
98	2	6		149	43	47
99	3	3	(3T1)	150	40	50
100	6	2		151	37	47
101	9	3		152	34	44
102	12	6		153	31	41
103	15	9		154	28	38
104	18	12		155	25	35
105	21	15		156	22	32
106	24	18		157	19	29
107	27	21		158	16	26
108	30	24		159	13	23
109	33	27		160	10	20
110	36	30		161	7	17
111	39	33		162	4	14
112	42	36		163	3	11
113	45	39		164	4	8
114	48	42		165	5	5 (5T1)
115	47	45		166	8	4
116	44	48		167	11	3
117	41	49		168	14	4
118	38	46		169	17	7
119	35	43		170	20	10
120	32	40		171	23	13
121	29	37		172	26	16
122	26	34		173	29	19
123	23	31		174	32	22
124	20	28		175	35	25
125	17	25		176	38	28
126	14	22		177	41	31
127	11	19		178	44	34
128	8	16		179	47	37
129	5	13		180	48	40
130	2	10	(2T2 for I)	181	45	43
131	3	7		182	42	46
132	4	4	(4T1)	183	39	49
133	7	3		184	36	48
134	10	2	(2T2 for II)	185	33	45
135	13	5		186	30	42
136	16	8		187	27	39
137	19	11		188	24	36
138	22	14		189	21	33
139	25	17		190	18	30
140	28	20		191	15	27
141	31	23		192	12	24
142	34	26		193	9	21
143	37	29		194	6	18

FR/GCF	I	II		FR/GCF	I	II	
195	3	15	(3T2 for I)	246	46	38	
196	4	12		247	43	41	
197	5	9		248	40	44	
198	6	6	(6T1)	249	37	47	
199	9	5		250	34	50	
200	12	4		251	31	47	
201	15	3	(3T2 for II)	252	28	44	
202	18	6		253	25	41	
203	21	9		254	22	38	
204	24	12		255	19	35	
205	27	15		256	16	32	
206	30	18		257	13	29	
207	33	21		258	10	26	
208	36	24		259	7	23	
209	39	27		260	4	20	(4T2 for II)
210	42	30		261	5	17	
211	45	33		262	6	14	
212	48	36		263	7	11	
213	47	39		264	8	8	(8T1)
214	44	42		265	11	7	
215	41	45		266	14	6	
216	38	48		267	17	5	
217	35	49		268	20	4	(4T2 for I)
218	32	46		269	23	7	
219	29	43		270	26	10	
220	26	40		271	29	13	
221	23	37		272	32	16	
222	20	34		273	35	19	
223	17	31		274	38	22	
224	14	28		275	41	25	
225	11	25		276	44	28	
226	8	22		277	47	31	
227	5	19		278	48	34	
228	4	16		279	45	37	
229	5	13		280	42	40	
230	6	10		281	39	43	
231	7	7	(7T1)	282	36	46	
232	10	6		283	33	49	
233	13	5		284	30	48	
234	16	4		285	27	45	
235	19	5		286	24	42	
236	22	8		287	21	39	
237	25	11		288	18	36	
238	28	14		289	15	33	
239	31	17		290	12	30	
240	34	20		291	9	27	
241	37	23		292	6	24	
242	40	26		293	5	21	
243	43	29		294	6	18	
244	46	32		295	7	15	
245	49	35		296	8	12	

FR/GCF	I	II		FR/GCF	I	II	
297	9	9	(9T1)	350	28	50	
298	12	8		351	25	47	
299	15	7		352	22	44	
300	18	6		353	19	41	
301	21	5		354	16	38	
302	24	6		355	13	35	
303	27	9		356	10	32	
304	30	12		357	7	29	
305	33	15		358	6	26	
306	36	18		359	7	23	
307	39	21		360	8	20	
308	42	24		361	9	17	
309	45	27		362	10	14	
310	48	30		363	11	11	(11T1)
311	47	33		364	14	10	
312	44	36		365	17	9	
313	41	39		366	20	8	
314	38	42		367	23	7	
315	35	45		368	26	6	
316	32	48		369	29	7	
317	29	49		370	32	10	
318	26	46		371	35	13	
319	23	43		372	38	16	
320	20	40		373	41	19	
321	17	37		374	44	22	
322	14	34		375	47	25	
323	11	31		376	48	28	
324	8	28		377	45	31	
325	5	25	(5T2 for I)	378	42	34	
326	6	22		379	39	37	
327	7	19		380	36	40	
328	8	16		381	33	43	
329	9	13		382	30	46	
330	10	10	(10T1)	383	27	49	
331	13	9		384	24	48	
332	16	8		385	21	45	
333	19	7		386	18	42	
334	22	6		387	15	39	
335	25	5	(5T2 for II)	388	12	36	
336	28	8		389	9	33	
337	31	11		390	6	30	(6T2 for I)
338	34	14		391	7	27	
339	37	17		392	8	24	
340	40	20		393	9	21	
341	43	23		394	10	18	
342	46	26		395	11	15	
343	49	29		396	12	12	(12T1)
344	46	32		397	15	11	
345	43	35		398	18	10	
346	40	38		399	21	9	
347	37	41		400	24	8	
348	34	44		401	27	7	
349	31	47					

FR/GCF	I	II
402	30	6 (6T2 for II)
403	33	9
404	36	12
405	39	15
406	42	18
407	45	21
408	48	24
409	47	27
410	44	30
411	41	33
412	38	36
413	35	39
414	32	42
415	29	45
416	26	48
417	23	49
418	20	46
419	17	43
420	14	40
421	11	37
422	8	34
423	7	31
424	8	28
425	9	25
426	10	22
427	11	19
428	12	16
429	13 (13T1)	13 (13T1)
430	16	12
431	19	11
432	22	10
433	25	9
434	28	8
435	31	7
436	34	8
437	37	11
438	40	14
439	43	17
440	46	20
441	49	23
442	46	26
443	43	29
444	40	32
445	37	35
446	34	38
447	31	41
448	28	44
449	25	47
450	22	50
451	19	47

FR/GCF	I	II
452	16	44
453	13	41
454	10	38
455	7 (7T2 for I)	35 (7T2 for I)
456	8	32
457	9	29
458	10	26
459	11	23
460	12	20
461	13	17
462	14 (14T1)	14 (14T1)
463	17	13
464	20	12
465	23	11
466	26	10
467	29	9
468	32	8
469	35 (7Y2 for II)	7 (7Y2 for II)
470	38	10
471	41	13
472	44	16
473	47	19
474	48	22
475	45	25
476	42	28
477	39	31
478	36	34
479	33	37
480	30	40
481	27	43
482	24	46
483	21	49
484	18	48
485	15	45
486	12	42
487	9	39
488	8	36
489	9	33
490	10	30
491	11	27
492	12	24
493	13	21
494	14	18
495	15 (15T1)	15 (15T1)
496	18	14
497	21	13
498	24	12
499	27	11
500	30	10

ETC.

INTERMOD FREQUENCIES FOR RFI SURVEY MONITORING

FR/GCF = 1 through 500

FR = monitor receiver frequency

GCF = greatest common factor between the two test transmit frequencies.

INTERMOD ORDER		FR/GCF									
2	I	32	66	98	130						
	II	34	66	100	134						
3	I	1	97	99	131	163	195				
	II	1	99	101	133	167	201				
4	I	34	64	132	162	164	196	228	260		
	II	32	68	132	166	168	200	234	268		
5	I	31	67	129	165	197	227	229	261	293	325
	II	35	65	135	165	199	233	235	267	301	335
6	I	2	96	100	194	198	230	262	292	294	326
		358	390								
	II	2	98	102	198	202	232	266	300	302	334
		368	402								
7	I	35	63	133	161	231	259	263	295	327	357
		359	391	423	455						
	II	31	69	131	169	231	265	265	299	333	367
		369	401	435	469						
8	I	30	64	128	164	226	264	296	324	328	360
		392	422	424	456	488					
	II	36	68	136	166	236	264	298	332	336	366
		400	434	436	468						
9	I	3	95	101	193	199	291	297	329	361	389
		393	425	457	487	489					
	II	3	97	103	197	203	297	303	331	365	399
		403	433	467							
10	I	36	62	134	160	232	258	330	356	362	394
		426	454	458	490						
	II	30	70	130	170	230	270	330	364	370	398
		432	466	470	500						
11	I	29	69	127	167	225	265	323	363	395	421
		427	459	491							
	II	37	63	137	163	237	263	337	363	397	431
		437	465	499							
12	I	4	94	102	192	200	290	298	388	396	428
		460	486								
	II	4	96	104	196	204	296	304	396	404	430
		464	498								

INTERMOD
ORDER

FR/GCF

13	I	37 461	61 493	135	159	229	257	331	355	429	453
	II	29 471	71 497	129	171	233	271	329	371	429	463
14	I	28 494	70	126	168	224	266	322	364	420	462
	II	38 496	62	138	162	238	262	338	362	438	462
15	I	5 495	93	103	191	201	289	299	387	397	485
	II	5	95	105	195	205	295	305	395	405	495
16	I	38	60	136	158	234	256	332	354	430	452
	II	28	72	128	172	228	272	328	372	428	472
17	I	27	71	125	169	223	267	321	365	419	463
	II	39	61	139	161	239	261	339	361	439	461
18	I	6 496	92	104	190	202	288	300	386	398	484
	II	6	94	106	194	206	294	306	394	406	494
19	I	39	59	137	157	235	255	333	353	431	451
	II	27	73	127	173	227	273	327	373	427	473
20	I	26	72	124	170	222	268	320	366	418	464
	II	40	60	140	160	240	260	340	360	440	460
21	I	7 497	91	105	189	203	287	301	385	399	483
	II	7	93	107	193	207	293	307	393	407	493
22	I	40	58	138	156	236	254	334	352	426	450
	II	26	74	126	174	226	274	326	374	432	474
23	I	25	73	123	171	221	269	319	367	417	465
	II	41	59	141	159	241	259	341	359	441	459
24	I	8 498	90	106	188	204	286	302	384	400	482
	II	8	92	108	192	208	292	308	392	408	492
25	I	41	57	139	155	237	253	335	351	433	449
	II	25	75	125	175	225	275	325	375	425	475
26	I	26	74	122	172	220	270	318	368	416	458
	II	42	58	142	158	242	258	342	358	442	466
27	I	9 499	89	107	187	205	285	303	383	401	481
	II	9	91	109	191	209	291	309	391	409	491

INTERMOD ORDER		FR/GCF									
28	I	42	56	140	154	238	252	336	350	434	448
	II	24	76	124	176	224	276	324	376	424	476
29	I	23	75	121	173	219	271	317	369	415	467
	II	43	57	143	157	243	257	343	357	443	457
30	I	10	88	108	186	206	284	304	382	402	480
	II	500 10	90	110	190	210	290	310	390	410	490
31	I	43	55	141	153	239	251	337	349	435	447
	II	23	77	123	177	223	277	323	377	423	477
32	I	22	76	120	174	218	272	316	370	414	468
	II	44	56	144	156	244	256	344	356	444	456
33	I	11	87	109	185	207	283	305	381	403	479
	II	11	89	111	189	211	289	311	389	411	489
34	I	44	54	142	152	240	250	338	348	436	446
	II	22	78	122	178	222	278	322	378	422	478
35	I	21	77	119	175	217	255	315	371	413	469
	II	45	55	145	155	245	273	345	355	445	455
36	I	12	86	110	184	208	282	306	380	404	478
	II	12	88	112	188	212	288	312	388	412	488
37	I	45	53	143	151	241	249	339	347	437	445
	II	21	79	121	179	221	279	321	379	421	479
38	I	20	78	118	154	216	274	314	372	412	470
	II	46	54	146	176	246	254	346	354	446	454
39	I	13	85	111	183	209	281	307	379	405	477
	II	13	87	113	187	213	287	313	387	413	487
40	I	46	52	144	150	242	248	340	346	438	444
	II	20	80	120	180	220	280	320	380	430	480
41	I	19	79	117	177	215	275	313	373	411	471
	II	47	53	147	153	247	253	347	353	447	453
42	I	14	84	112	182	210	280	308	378	406	476
	II	14	86	114	186	214	286	314	386	414	486
43	I	47	51	145	149	243	247	341	345	439	443
	II	19	81	119	181	219	281	319	381	419	481
44	I	18	80	116	178	214	276	312	374	410	472
	II	48	52	148	152	248	252	348	352	448	452
45	I	15	83	113	181	211	279	309	377	407	475
	II	15	85	115	185	215	285	315	385	415	485

**INTERMOD
ORDER**

FR/GCF

46	I	48	50	146	148	244	246	342	344	440	442
	II	18	82	118	182	218	282	318	382	418	482
47	I	17	81	115	179	213	277	311	375	409	473
	I	49	51	149	151	249	251	349	351	449	451
48	I	16	82	114	180	212	278	310	376	408	474
	II	16	84	116	184	216	284	316	384	416	484
49	I	49	147	245	343	441					
	II	17	83	117	183	217	283	317	383	417	483
50	I	None — exceeds maximum possible of 49.									
	II	50	150	250	350	450					

XIV REAL-TIME EVALUATION OF SURVEY DATA

An impressive feature of the ship RFI survey to discover the magnitude of the interference problem by applying the tools described in Section XIII is that it is unnecessary to delay a decision until the data can be evaluated at some later time. Independent of which procedure option is used, the RFI investigator can make reliable statements immediately about the likelihood of reduced HF reception capability due to intermodulation interference triggered by a number of simultaneous HF transmissions.

If the intermodulation signals become undetectable at orders above the 7th, and even the 5th order signals are weak and variable, the potential for RFI interference to reception of incoming HF traffic is low. The situation does not justify expenditure of time and money to determine the sources of the interference signals.

But, if the order of the interference with significant signal strength is well above the 7th, the RFI potential is great enough to require location of the worst sources as part of the survey. It is very difficult to attempt a quantitative, reliable estimate of just how severe the reception error rate increase will be under operational communication conditions. More worthwhile is the general statement that if important high order intermodulation signals are observed during the RFI survey, an attempt must be made to find the worst sources of interference so they can be removed permanently. The higher the order of the detectable intermodulation signal, the more urgent the location and removal of the source generating it becomes.

As a practical matter, if there are strong intermodulation signals with orders in the 20's or 30's, there is no question of whether the RFI potential is bad enough to warrant source location. But it is inefficient to spend much time searching for the absolute maximum order detectable. Such information is quite academic, unless difficulties with false nulls during direction finding attempts at locating the worst source force the use of higher orders to eliminate the possibility of more than one source for the intermod signal being traced.

XV TESTS DEMANDED BY DOWN-CHECK EVALUATION

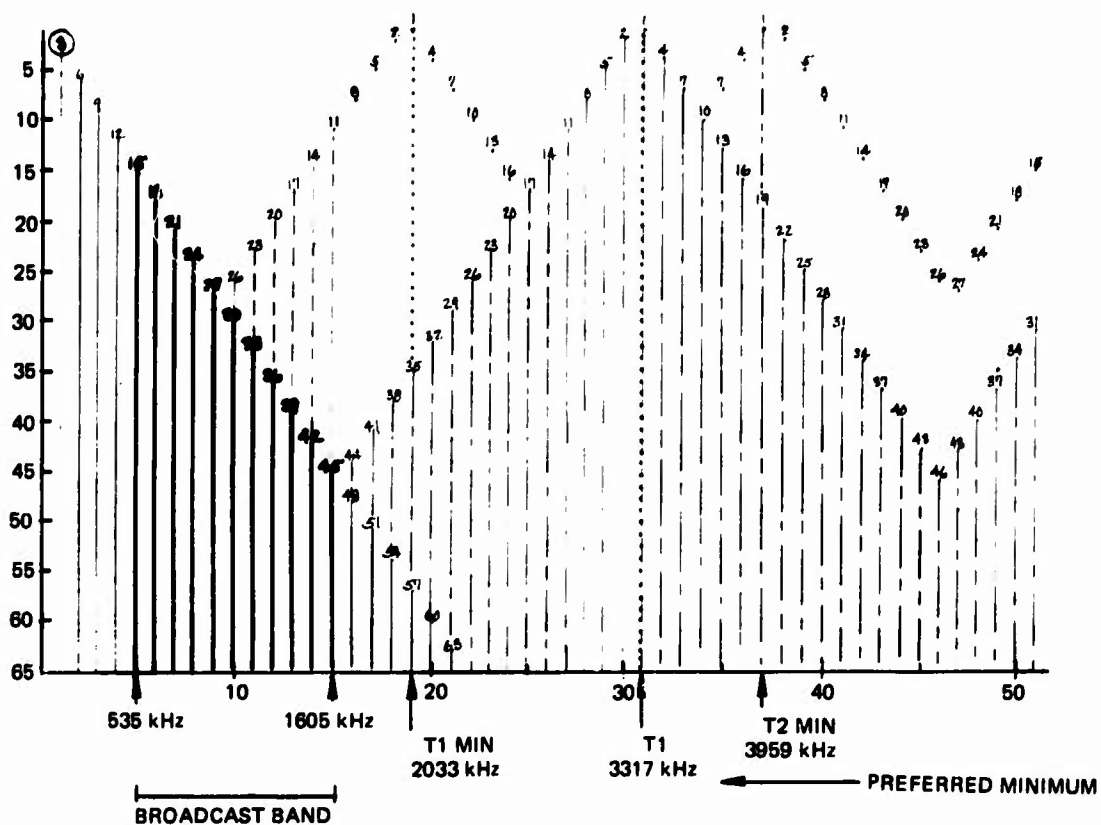
Assuming there are significantly strong intermodulation signals with orders well above the 7th detected at HF frequencies, the RFI survey emphasis must be shifted to a worst source location mode. As pointed out in Section VI, the required conditions for most reliable and effective direction finding are the use of high order intermodulation signals and the concentration on these signals in the standard AM broadcast band, 535 to 1635 kHz.

In the interest of making sure that the investigation of RFI potential is made with 50 as a maximum value of intermodulation order and the difference between the orders of adjacent intermodulation signals 3 or less, the transmit frequency pairs have been carefully chosen. But when that portion of the intermodulation spectrum over the broadcast band is looked at critically, it is found that the situation is quite unsatisfactory for a direction finding application. The precise relationships which forced the very orderly pattern of the intermodulation signals described in Section XIII allow the greatest common factor between transmit frequencies. . . .and the separation between adjacent intermodulation signals. . . .to increase from a minimum of 61 kHz (with the transmit frequencies at the low end of the HF band) to a maximum of about 450 kHz (with transmissions at the high end). Furthermore, not only does the number of intermodulation signals in the broadcast band change from 18 to 2, but the range of intermod orders varies from 20 to 48 through only 6 and 9.

The occurrence of intermodulation signals in the broadcast band can be controlled by making the greatest common factor a constant and allowing the maximum value of intermodulation signal order to vary. With the constant greatest common factor set at 107 kHz there are always 11 intermods in the broadcast band. They are always at the same frequencies. If the minimum possible transmit frequency pair is used. . . .2033 and 3959 kHz. . . .the intermod signal frequencies and their respective orders become

<u>Frequency, kHz</u>	<u>Order</u>
535	15
642	18
749	21
856	24
963	27
1070	26
1177	23

INTERMODULATION SPECTRUM CHART – BROADCAST FREQUENCIES



TEST TRANSMISSION FREQUENCY PAIRS AND ASSOCIATED QMAX

QC = 3, Type I, with Constant GCF

GCF = 107 kHz throughout

T1 kHz	T2 kHz	QMAX	T1 kHz	T2 kHz	QMAX
2033	3959	28	6848	13589	95
2140	4173	29	6955	13803	97
2247	4387	31	7062	14017	98
2354	4601	32	7169	14231	100
2461	4815	34	7276	14445	101
2568	5029	35	7383	14659	103
2675	5243	37	7490	14873	104
2782	5457	38	7597	15087	106
2889	5671	40	7704	15301	107
2996	5885	41	7811	15515	109
3103	6099	43	7918	15729	110
3210	6313	44	8025	15943	112
3317	6527	46	8132	16157	113
3424	6741	47	8239	16371	115
3531	6955	49	8346	16585	116
3638	7169	50	8453	16799	118
3745	7383	52	8560	17013	119
3852	7597	53	8667	17227	121
3959	7811	55	8774	17441	122
4066	8025	56	8881	17655	124
4173	8239	58	8988	17869	125
4280	8453	59	9095	18083	127
4387	8667	61	9202	18297	128
4494	8881	62	9309	18511	130
4601	9095	64	9416	18725	131
4708	9309	65	9523	18939	133
4815	9523	67	9630	19153	134
4922	9737	68	9737	19367	136
5029	9951	70	9844	19581	137
5136	10165	71	9951	19795	139
5243	10379	73	10058	20009	140
5350	10593	74	10165	20223	142
5457	10807	76	10272	20437	143
5564	11021	77	10379	20651	145
5671	11235	79	10486	20865	146
5778	11449	80	10593	21079	148
5885	11663	82	10700	21293	149
5992	11877	83	10807	21507	151
6099	12091	85	10914	21721	152
6206	12305	86	11021	21935	154
6313	12519	88	11128	22149	155
6420	12733	89	11235	22363	157
6527	12947	91	11342	22577	158
6634	13161	92	11449	22791	160
6741	13375	94	11556	23005	161

← Preferred minimum
for protection of
intermod spectrum
between 535 and
1605 kHz.

T1 kHz	T2 kHz	QMAX
11663	23219	163
11770	23433	164
11877	23647	166
11984	23861	167
12091	24075	169
12198	24289	170
12305	24503	172
12412	24717	173
12519	24931	175
12626	25145	176
12733	25359	178
12840	25573	179
12947	25787	181
13054	26001	182
13161	26215	184
13268	26429	185
13375	26643	187
13482	26857	188
13589	27071	190
13696	27285	191
13803	27499	193
13910	27713	194
14017	27927	196
14124	28141	197
14231	28355	199
14338	28569	200
14445	28783	202
14552	28997	203
14659	29211	205
14766	29425	206
14873	29639	208
14980	29853	209

<u>Frequency, kHz</u>	<u>Order</u>
1284	20
1391	17
1498	14
1605	11

If the minimum transmit frequencies are made 3317 and 6527 kHz a fixed, basic combination of orders and frequencies becomes available. Now no further change in the transmit frequency pairs across the HF band has any effect on the orders at the 11 intermodulation signal frequencies in the broadcast band. The constant frequency/order sequence is

<u>Frequency, kHz</u>	<u>Order</u>
535	15
642	18
749	21
856	24
963	27
1070	30
1177	33
1284	36
1391	39
1498	42
1605	45

Two fortunate situations result from juggling the transmit frequencies in a manner different from that employed to derive the spectrum for evaluating the ship's latent intermodulation interference problems. The maximum possible value of intermodulation order is unimportant. The bundle of adjacent intermods which increase in order by increments of 3 as their frequencies vary from the minimum equal to the greatest common factor is the only one remaining fixed, independent of transmit frequencies.

The only disadvantage of this procedure for establishing a reasonable number of useful intermodulation frequencies and orders in the broadcast band is the necessity of another group of transmit test frequency pairs. But the advantages of rigidly controlled frequencies for use in locating the worst sources of intermodulation interference quickly are worth the small inconvenience.

One final point: if a 2 to 6 MHz transmit antenna must be excited at two frequencies simultaneously, the combination of 2996 and 5885 should be used to minimize the contamination of the basic intermodulation orders at the 11 broadcast frequencies. Only two changes are made in the frequency/order list: at 1498 kHz the order is now 41 instead of 42; at 1605 kHz the order decreases from 45 to 38.

XVI RELIANCE ON HIGH INTERMOD ORDER AT LOW FREQUENCY FOR WORST SOURCE LOCATION

Description of a typical situation is the clearest way to present details of locating the worst source of intermodulation interference. Suppose in the course of conducting the RFI survey the investigator discovers an easily detectable 21st order intermod at 6097 kHz while a 2 to 6 MHz broadcast transmitting antenna is excited by two simultaneous CW test transmissions at 2211 and 4355 kHz. The greatest common factor for these frequencies is 67 kHz, indicating that all intermodulation signal frequencies are multiples of 67. Not only does the intermod continue to be easily received at 6097 kHz as the monitoring receiver is connected to all HF receiving antennas, but other 21st orders appear with reasonable strength also on 7035 and 12663 kHz. Reception is weaker and more variable at the 23rd order intermodulation signal frequencies 4891 and 8509 kHz.

These data confirm the RFI potential for this ship to be great enough to justify location of the worst source. The investigator realizes, after consulting the tables, that the 21st order intermod closest to the broadcast band is $7 \times 67 = 469$ kHz. Even the 23rd order has no signal in the broadcast band; its nearest intermodulation frequency is $25 \times 67 = 1675$ kHz. However, when the special transmit frequency combination list compiled for the 11 intermodulation signal broadcast band frequencies is reviewed, the investigator chooses 2996 and 5885 kHz, greatest common factor of 107 kHz. The 21st order occurs at 749 kHz with the new transmit frequency pair.

When the investigator tunes the modified broadcast receiver to 749 kHz he is disturbed to find that a local broadcast station on 750 kHz is so strong that he would prefer to choose another intermod frequency rather than attempt direction finding on the worst source with such a distraction. He observes the 24th order at 856 kHz; useable, but weak. At 963 kHz he finds the 27th order to be not only free of interference but stronger than the 24th. This is the frequency he uses to locate the worst source.

XVII HIGHEST SIGNIFICANT ORDER RECHECK

Continuing with the example in the previous section, the RFI investigator uses the modified broadcast receiver set at 963 kHz to locate the general area of the worst intermodulation interference source. From widely different parts of the ship he finds null direction for the 27th order signal. There is some advantage in making the initial direction finding cuts from positions off the ship, but if the ship being surveyed is not alongside a dock this procedure will be awkward or even impossible.

Once the general area of the worst source has been established, the specific location is found by continuing the direction finding process carefully. Because there is neither audio gain control nor AGC in the modified receiver, accuracy of close-in nulls depends entirely on utilizing only the minimum signal by constantly decreasing the manually controlled signal level in the receiver. Confirmation of just which one of several possible intermodulation interference sources is the culprit can be had by moving or applying pressure to each in turn while observing correlated changes in signal level on the temporarily fixed DF receiver. In some cases the worst source will not be in a metallic item on the ship's topside. For instance, the DF-ing procedure could indicate the source as a transmitting or receiving antenna itself. But, if no inspection nor manipulation of the antenna confirms the source location, there is now a strong indication the actual source is inside the transmit or receive antenna system itself. . . . connectors, matching circuit components and their interconnections are all typically suspect. (A useful trick in the final stages of source location is the shift of the DF receiver to increasingly higher order frequencies than the one used at the beginning of the location process. Although the signal level of extreme orders is insignificantly small and undetectable during the survey phase, when the location receiver is very close to the worst source the signal level is great enough to be useful, increasing the chance of locating the worst of an unknown total number of intermodulation interference signal sources.)

Once the worst source is located and its signal generating capability destroyed, a new phase of the RFI survey is entered. A check must be made of the new conditions with only the second worst source of the unknown total being responsible for the highest order detectable intermodulation signal. In the present example, the 27th order was used to locate the worst source. An immediate recheck can be made with the DF receiver after the worst source is found by tuning it to the well-known and fixed frequency/order combinations in the broadcast band the 24th, 21st, 18th, and 15th orders are available for inspection.

In addition to any such preliminary recheck it is prudent to return to the original survey transmit frequency pair and reinvestigate with the monitoring receiver what the highest order intermod signal with significant level is now. It should not be surprising if the results of reiterating the monitoring process reveal that the new highest order is considerably lower, say a drop from 27th to 15th or even 11th. The reiteration of the location phase for the second worst intermod signal source may not be as clear cut as for the worst source. With the use of lower order signals for DF-ing there is a greater probability of contributions from more than one source, but working with 15th order signals is far better than dropping down in order to 3rd or 5th orders where multiple sources are quite likely.

It is difficult to give general guidance which covers all possible circumstances in the field. Both survey and location phases of the investigation must be done over and over until there is no benefit justifying any further cycling. As more cycles are attempted, location of sources will be more difficult and any improvement due to removal of sources will be less impressive.

XVIII TRANSLATION FROM SURVEY RESULTS TO SHIPYARD GUIDANCE

Though probably difficult for the technically oriented RFI investigator involved in the very interesting details of the survey, it must be remembered that the primary purpose is the obtaining of information which provides reliable, nontechnical answers to a few basic questions about the surveyed ship. The ship's communications reliability under operational conditions depends on the protection of the low error rate reception capability inherent in the communications system design, installation and operation within acceptable restrictions, in spite of the simultaneous transmissions handling outgoing traffic. For the most part there will be little interest in strictly technical information shown by the people concerned with the operational readiness of the ship. They are anxious to get direct answers to the following questions:

- (1) Is the apparent communications performance of this ship in danger of being decreased when she is performing her mission?
- (2) What causes make the performance poorer than expected?
- (3) Can these causes be listed in order of importance?
- (4) How much time and effort must be spent in removing each of the causes?
- (5) Once the causes are removed, what assurance can be given that operational communications has returned to the designed capability?

Question (1) can be given a yes or no answer by the results of interference signal monitoring during the first phase of the survey. If there are intermodulation signal orders greater than the 7th, the ship's communications performance will be inhibited. The degree to which performance is decreased becomes more serious rapidly as the orders of intermodulation signals go higher than 7.

Questions (2) and (3) are answered by the specific items found during the location phase of the survey. It is most important the location procedure be conducted to rank the sources found as worst, second worst, third worst, etc. However, this ranking is done solely on the basis of interference probability and signal levels; there is no valid reason why the worst intermodulation source should be the most difficult or expensive to remove. On the contrary, it may be the source ranked third or fourth in importance which is the one requiring the greatest trouble to eliminate.

Answering Question (4) is entirely up to the shipyard estimators who have been given the ranked list of interference sources. Some solutions may require temporary fixes to be followed up by permanent ones much later. The estimators can be assisted greatly by information recommending solutions based on technical grounds. Such recommendations should include several options designated as preferred, acceptable, and quick-and-dirty fixes.

Question (5) is discussed in Section XIX and includes evaluation of the communications performance soon after all, or at least the most important, interference sources are removed as well as what the ship's communication people can do to know whether the intermodulation interference threat is still acceptably low.

XIX NEED FOR RECHECK AFTER FIXES

In all past attempts to solve the problem on intermodulation interference to shipboard communications it has been difficult to prove what real benefits resulted from location of proven sources and their removal. Until recently any tests to prove effectiveness have been limited to measurements of signal levels at low intermodulation orders. It is now realized that, just as the location and rank ordering of interference sources have now been improved greatly by emphasizing the highest detectable orders, the proof of better communications capability is best obtained by comparing the highest detectable orders before and after fixes are accomplished. Therefore, a post-fix RFI survey is necessary to get this information. The time and effort required for this second survey can be made much less than for the original one by conducting tests identical

in transmit frequencies, antennas, and monitoring conditions with those which produced the indication of interference too great to be ignored during the original survey.

An important side benefit of the post-fix survey is the possibility of spotlighting interference sources not present during the original survey and due to changes made during the period between surveys. So, even though the post-fix survey gives disappointing results, the cause of interference is probably in new intermodulation sources rather than unsuccessful elimination of those located and ranked previously. Of course, any new sources must be located and eliminated.

An obvious extension of the purpose for the post-fix RFI survey is the consideration of the ship's communications people making their own brief RFI survey during deployment as a preventive maintenance check whenever the opportunity occurs. Familiarity with the procedure will pay off if severe interference to reception of operational traffic suddenly appears. Then the crew can conduct the search for intermodulation sources themselves and, in most instances, solve the problem rapidly without resorting to requesting assistance or enduring the poorer communications effectiveness until returning from a mission.

XX CONDITIONS FOR STAMP OF APPROVAL

Inevitably, the question is asked regarding how strong an intermodulation signal can be before a ship's HF communications system cannot be approved as operationally acceptable. Throughout this document the order of the intermodulation signal has been stressed; references to signal strength have been made quite general deliberately. Such terms as "detectable" and "significantly strong" are common. The reason for avoiding the use of quantitative data expressed in terms of dB below a milliwatt or dB above a microvolt is that it is unnecessary to be so accurate to assess the possible RFI situation when an operational traffic load is handled by a number of simultaneous, continuous transmissions and several different reception facilities on the same ship.

The two important aspects of intermodulation interference are (1) on how many frequencies will intermodulation signals appear? and (2) what is a valid comparison of incoming traffic signal and intermodulation signal levels?

It is well known that the number of intermodulation signals occupying a given portion of the radio frequency spectrum increases rapidly with an increase in the number of simultaneous transmissions. But the mathematics necessary to handle 3 or more transmissions is horribly complicated. In order to derive a practical use of test transmissions during an RFI survey, advantage was taken of the comparatively simple mathematical process where only two transmitters are

employed. The number of possible intermodulation signals during the survey across the 3 to 30 MHz spectrum is 28000 divided by the greatest common factor between the two test transmit frequencies. The limit of intermodulation order occurring on the intermodulation signal frequencies is the sum of the two transmit frequencies divided by twice the greatest common factor. Now, with the choice of a transmit frequency pair from the "cook book" list provided. . . .where the intermodulation order limit is forced to be 50. . . .the number of possible intermod frequencies will be between 60 and 450, depending on the greatest common factor. With a frequency pair yielding, say, 200 possible intermodulation signals in the HF band (4620 and 9100 kHz; greatest common factor of 140 kHz), the monitoring receiver investigation of only those frequencies which are multiples of 140 kHz is concerned not with which signals are the strongest but with how high an intermodulation signal order can be received. It has already been stated several times that, if an order of 35 can be detected by the monitoring receiver, the device on the ship which causes the 35th order is such a potent source of intermodulation interference that it must be located and destroyed. Once that has been done, if a second sweep with the monitoring receiver reveals that a 21st order can now be detected, its source must be located and removed. The goal of the survey is to limit significantly strong (i.e. detectable) intermodulation signals to the 7th order and below.

With the help of the intermodulation spectrum picture an accurate idea of the change in intermod numbers can be found. Since the greatest common factor due to the choice of the sample transmit pair is 140 kHz, the 2000 to 30000 kHz spectrum occupies the normalized spread from 14 to 214. There are 140 intermods below the 35th order (70 percent of the total possible), 84 below the 21st order (42 percent of the total possible), and 28 below the 7th order (14 percent of the total possible). Thus, an improvement factor of 5 is obtained in decreasing the detectable intermod signal orders from 35th to 7th.

Now that the intermodulation interference has been controlled to the extent that only the 7th orders and below are detectable by the ship's receivers, it is worthwhile to consider the intermod signal levels. Whatever the level of the intermod signals falling on traffic receive frequencies, the strengths will be much more constant than the incoming signal from off ship. At a given frequency the coupling between intermod source and receiving antenna is fixed, whereas the losses on the propagation path followed by the traffic signal are variable. Therefore, the ratio of traffic signal to intermod signal is highly variable. It will be so great a ratio when the correct

traffic signal frequency for the path is used that the effect on error rate caused by the intermodulation interference will be insignificant. Only when the propagation path changes cause the incoming signal level to drop drastically will the traffic to intermod signal ratio decrease to the point where reception error rate is affected by the local interference. When this situation has occurred the traffic signal frequency must be changed to follow the effect of propagation conditions anyway. This argument is the basis for not attempting to categorize intermod signal levels in quantitative terms during the RFI survey. It follows, then, that whenever possible the determination of highest order detectable intermodulation signals by a monitoring receiver should be made at frequencies where natural noise from atmospherics is a minimum. In addition, since the test transmit mode is CW and the intermodulation signals are also CW, a narrowband audio filter will assist detection even with greater than minimum atmospheric noise.

XXI LIMITATIONS ON SURVEY VALIDITY

The motivating force behind an RFI survey of a ship is the assurance it can give to those relying on the ship's communications performance under operational conditions during a mission. But a rather disturbing factor is that the lack of important self-generated intermodulation interference at the time when the survey is made cannot be considered proof that the interference threats will always be so low.

If, in preparation for overhaul work at a shipyard, an RFI survey is conducted several months before the scheduled availability period and it is found that the potential for interference is not significant, no RFI-oriented work will be included in the shipyard schedule. However, if during the period between RFI survey and shipyard arrival an important source of intermodulation interference is inadvertently manufactured on the surveyed ship, the resulting interference problem will not be solved during the shipyard period. The situation will not become evident until the post-shipyard RFI survey just prior to release of the ship as operationally ready.

Therefore, it is most advantageous if the RFI survey is made with a minimum pre-shipyard delay. An additional protection for the survey validity will come also from the ship's communications people being alert to the possibility of the intermodulation interference problem and conducting their own mini-survey. . . .complete with location of the source, if necessary. . . .during the interval between "official RFI survey" and advent of shipyard work.

XXII APPENDIX

1. Preface

Feedback from a number of engineers who had reviewed the first draft of this document indicated the need for expansion of the survey procedure to include several useful items. Although the original text could have been rewritten, it was decided to add another appendix-like section rather than disturb the first draft. This decision was justified because the previous 21 sections had been written deliberately for a broad and varied audience. Most of the items in this appendix will interest only a small percentage of the readers.

It is not suprising that several engineers, becoming interested in the mathematics involved, have expressed disappointment that there are no equations in the first draft. Although these can be constructed by an awkward translation from the plain language step-by-step description in the original text, this appendix includes the complete numbers theory derivation.

The most consistent comment had to do with the difficulty in getting transmit test frequency allocations which conformed to the very rigid relationships demanded by the controlled intermodulation spectrum with the greatest common factor frequency's order a 3rd and the maximum possible order value set at 50. An investigation of the general relationships has provided a table in which a considerable number of transmit test frequency pairs are listed. The order at the greatest common factor frequency is still 3, but the wide choice of maximum possible order from 3 to 140 makes the great variety of frequency pairs possible.

The original text, in discussing the means of controlling worst source location transmit test frequencies, again limits severely the allocation criteria by insisting that there be 11 intermodulation signals in the standard AM broadcast band. The obvious benefits require a fixed greatest common factor of 107 kHz. If this restriction is lifted, the number of broadcast band intermods becomes variable, and the difficulty of obtaining transmit test frequencies is eased. A table has been prepared which allows a choice of greatest common factor dependent only on the number of intermods falling on broadcast band frequencies.

Restrictions placed on the choice of transmit test frequencies are further relaxed when one is willing to change the order of the intermodulation signal at the frequency equal to the greatest common factor. This has been done for orders from 4th through 9th. The calculation results for T1, T2, and maximum possible order are tabulated and require only a choice of a coefficient to yield the means for generating specific frequency lists similar to those appearing in the original text.

A simulated spectrum analyzer display has been constructed for the conditions where a 7th order intermod falls on the greatest common factor frequency and the maximum possible order is set near 50. This display is included for comparison with the original simulation for a 3rd order greatest common factor intermediate frequency. The comparison shows vividly how rapidly the usefulness of the controlled intermodulation spectrum deteriorates when the 3rd order at the greatest common factor frequency is abandoned.

Finally, a brief exercise is included which describes the procedure which must be followed when the RFI investigator asks, "Isn't it possible to choose T1 and T2 so that survey monitoring and worst source location requirements are satisfied simultaneously?"

2. Basic relationships of transmit and intermodulation signal frequencies

T2 always greater than T1 is a basic assumption.

Typical use of Euclidean algorithm:

$$T2 = (A1)T1 + B1; M1 = -(A1) \quad ; N1 = +1$$

$$T1 = (A2)B1 + B2; M2 = (A2)(A1) + 1; N2 = -(A2)$$

$$B1 = (A3)B2 + B3; M3 = M1 - (A3)M2; N3 = 1 - (A3)N2$$

$$B2 = (A4)B3 + B4; M4 = M2 - (A4)M3; N4 = N2 - (A4)N3$$

$$B3 = (A5)B4 + C; M5 = M3 - (A5)M4; N5 = N3 - (A5)N4$$

$$B4 = (A6)C + \text{zero}; M6 = M4 - (A6)M5; N6 = N4 - (A6)N5$$

$$|M6| = U2 \quad |N6| = U1$$

C is the greatest common factor shared by T1 and T2.

$$U1 = \frac{T1}{C} \quad ; U2 = \frac{T2}{C}$$

C is also the frequency increment separating all adjacent intermodulation frequencies from DC to light.

QMAX is the maximum possible value an intermodulation order can be over the frequency range from C through (QMAX)T1. Beyond (QMAX)T1 the situation is unpredictable.

$$QMAX = \frac{T1+T2}{2C} = \frac{U1+U2}{2} \quad ; \text{whole number only, remainder ignored.}$$

In the algorithm example all remainders B1, B2, B3, B4, C, and zero are qualified intermodulation frequencies. Therefore, they can be expressed in terms of T1 and T2 as

$$B1 = (M1)T1 + (N1)T2$$

$$B2 = (M2)T1 + (N2)T2$$

$$B3 = (M3)T1 + (N3)T2$$

$$B4 = (M4)T1 + (N4)T2$$

$$C = (MC)T1 + (NC)T2$$

$$\text{zero} = (MZ)T1 + (NZ)T2$$

Any suspected intermodulation frequency, R , can be qualified by $\frac{R}{C}$. If the quotient is a whole number, R is a qualified intermodulation frequency. As in the algorithm remainder frequencies, R can be expressed in terms of $T1$ and $T2$.

$$R = (MR)T1 + (NR)T2.$$

The order, Q at any qualified intermodulation frequency is the sum of the magnitudes of the $T1$ and $T2$ coefficients, ignoring the sign, as in $QB1 = |M1| + |N1|$, $QC = |MC| + |NC|$, $QR = |MR| + |NR|$.

Q will be the lowest order of all the intermodulation signals sharing the same qualified intermodulation frequency. (It is the lowest order intermod which controls the level of the intermodulation signal observed during the monitoring phase of the RFI survey.)

The lowest order for any intermod on a qualified intermod frequency, R , can be found only by calculating MR and NR and adding their magnitudes. A key factor is $S = \frac{R}{C}$. Then

$$S(MC) = D(MZ) + MR ; |MR| < \left| \frac{MZ}{Z} \right|, \text{ and}$$

$$S(NC) = D(NZ) + NR ; |NR| < \left| \frac{NZ}{2} \right|.$$

MR and NR can be positive or negative. Then

$$QR = |MR| + |NR|.$$

A necessary check to prove that MR and NR are indeed the coefficients for the lowest order intermod on R can be made by making the calculations

$$M = MR \pm n(U2) \text{ and}$$

$$N = NR \mp n(U1),$$

where n is any positive integer. If $|M| + |N|$ is less than $|MR| + |NR|$, the calculated order was not the lowest order. (Of course, if $R < (QMAX) T1$, the only check required is that $QR < QMAX$.)

A Type I intermod has M positive and N negative.

A Type II intermod has M negative and N positive.

A Type III intermod has M positive and N positive.

If it is desired to monitor only the intermodulation frequencies where a given intermod order, QR , occurs, all possible frequencies are quickly calculated from

$$R1 = (QR)T1 - H(T1+T2), \text{ where}$$

H is a positive whole number, including zero

$$HMAX = \frac{(QR)T1}{T1+T2}, \text{ ignoring any remainder;}$$

$$R_{II} = (QR)T_2 - J(T_1 + T_2), \text{ where}$$

J is a positive whole number, including zero

$$J_{MAX} = \frac{(QR)T_2}{T_1 + T_2}, \text{ ignoring any remainder; and}$$

$$R_{III} = (QR)T_2 - K(T_2 - T_1)$$

or

$$R_{III} = (QR)T_1 + L(T_2 - T_1), \text{ where}$$

K and L are positive whole numbers; minimum values are one, maximum values are $QR-1$.

NOTE: The "typical" algorithm used in this description of the numbers theory fundamentals of intermodulation has six steps. In general, the number of steps required, being dependent solely on the values of T_1 and T_2 , can be greater or less than six.

3. Additional combinations of T_1 and T_2 for $QC = 3, I$ and II

Considerable relief to the severe restrictions affecting allocations of T_1 and T_2 frequencies for the controlled intermodulation spectrum obtained from forcing $QC = 3$ can be found by simply changing the value of Q_{MAX} . But the basic expressions must be derived from the algorithm.

<u>$QC = 3, I; C = 2(T_1) - T_2$</u>	<u>M</u>	<u>N</u>
$T_2 = 1(T_1) + B1$	-1	+1
$T_1 = 1(B1) + C$	+2	-1
$B1 = (A3)C + \text{zero}$	-U2	+U1
$T_1 = (A3)C + C = [A3+1]C$		
$T_2 = [A3+1]C + (A3)C = [2(A3)+1]C$		
$Q_{MAX} = \frac{A3+1 + 2(A3)+1}{2} = \frac{3(A3)+2}{2}$		
ignore any remainder		

<u>$QC = 3, II; C = T_2 - 2(T_1)$</u>	<u>M</u>	<u>N</u>
$T_2 = 2(T_1) + C$	-2	+1
$T_1 = (A2)C + \text{zero}$	+U2	-U1
$T_1 = (A2)C$		
$T_2 = 2(A2)C + C = [2(A2)+1]C$		

$$Q_{MAX} = \frac{A_2 + 2(A_2) + 1}{2} = \frac{3(A_2) + 1}{2}$$

ignore any remainder

Now that the two series have yielded general expressions in terms of the algorithm coefficients A_2 and A_3 , these can be rewritten in the same form where more general factors are used.

$$QC = 3, I; C = 2(T_1) - T_2$$

$$T_1 = [X+1]C$$

$$T_2 = [2X+1]C$$

$$Q_{MAX} = \frac{3X+2}{2}, \text{ ignore any remainder}$$

$$QC = 3, II; C = T_2 - 2(T_1)$$

$$T_1 = (Y)C$$

$$T_2 = [2Y+1]C$$

$$Q_{MAX} = \frac{3Y+2}{2}, \text{ ignore any remainder}$$

It is now possible to generate a whole series of T_1 and T_2 pairs in terms of the greatest common factor, C . Each pair will automatically have a specific Q_{MAX} value associated with it as numbers are assigned X and Y . A table has been made where all values of Q_{MAX} are included between 3 and 140; actually, 140 does not represent the maximum limit. In spite of this great variety of T_1 and T_2 values, it is probably best to limit choices of Q_{MAX} to values between 35 and 65.

Note that the choice of the greatest common factor is open. However, T_1 must be above 2000 kHz and T_2 must be below 30000 kHz. So, once a choice has been made and the transmit frequencies have been determined in terms of C , it is a simple matter to calculate C_{MIN} and C_{MAX} . For example, let the value of Q_{MAX} be set at 65. From the table the transmit frequencies are

$$QC = 3, I \quad T_1 = 44C, \quad T_2 = 87C$$

$$QC = 3, II \quad T_1 = 43C, \quad T_2 = 87C$$

I. $\frac{2000}{44} = 45.4545$. For T_1 MIN to be greater than 2000 kHz, C_{MIN} must be 46 kHz. Then,

$$T_1 \text{ MIN} = (44)(46) = 2024 \text{ kHz.}$$

$$T_2 \text{ MIN} = (87)(46) = 4002 \text{ kHz.}$$

SUMMARY OF T1 AND T2 RELATIONSHIPS, RFI SURVEY

Order for 1M at GCF = 3rd

QC = 3, I; C = 2(T1) - T2		QC = 3, II; C = T2 - 2(T1)		
QMAX	T1 () C	T2 () C	T1 () C	QMAX
(T2 column is common to both cases)				
4	3	5	2	3
5	4	7	3	5
7	5	9	4	6
8	6	11	5	8
10	7	13	6	9
11	8	15	7	11
13	9	17	8	12
14	10	19	9	14
16	11	21	10	15
17	12	23	11	17
19	13	25	12	18
20	14	27	13	20
22	15	29	14	21
23	16	31	15	23
25	17	33	16	24
26	18	35	17	26
28	19	37	18	27
29	20	39	19	29
31	21	41	20	30
32	22	43	21	32
34	23	45	22	33
35	24	47	23	35
37	25	49	24	36
38	26	51	25	38
40	27	53	26	39
41	28	55	27	41
43	29	57	28	42
44	30	59	29	44
46	31	61	30	45
47	32	63	31	47
49	33	65	32	48
50	34	67	33	50
52	35	69	34	51
53	36	71	35	53
55	37	73	36	54
56	38	75	37	56
58	39	77	38	57
59	40	79	39	59
61	41	81	40	60
62	42	83	41	62
64	43	85	42	63
65	44	87	43	65
67	45	89	44	66
68	46	91	45	68
70	47	93	46	69

QMAX	T1 (°C)	T2 (°C)	T1 (°C)	QMAX
71	48	95	47	71
73	49	97	48	72
74	50	99	49	74
76	51	101	50	75
77	52	103	51	77
79	53	105	52	78
80	54	107	53	80
82	55	109	54	81
83	56	111	55	83
85	57	113	56	84
86	58	115	57	86
88	59	117	58	87
89	60	119	59	89
91	61	121	60	90
92	62	123	61	92
94	63	125	62	93
95	64	127	63	95
97	65	129	64	96
98	66	131	65	98
100	67	133	66	99
101	68	135	67	101
103	69	137	68	102
104	70	139	69	104
106	71	141	70	105
107	72	143	71	107
109	73	145	72	108
110	74	147	73	110
112	75	149	74	111
113	76	151	75	113
115	77	153	76	114
116	78	155	77	116
118	79	157	78	117
119	80	159	79	119
121	81	161	80	120
122	82	163	81	122
124	83	165	82	123
125	84	167	83	125
127	85	169	84	126
128	86	171	85	128
130	87	173	86	129
131	88	175	87	131
133	89	177	88	132
134	90	179	89	134
136	91	181	90	135
137	92	183	91	137
139	93	185	92	138
140	94	187	93	140

$$\frac{30000}{87} = 344.8276. \text{ For T2MAX to be less than 30000 kHz, CMAX must be 344 kHz.}$$

$$\text{Then, T2MAX} = (87)(344) = 29928 \text{ kHz.}$$

$$\text{T1MAX} = (44)(344) = 15136 \text{ kHz.}$$

$$\text{II. Similarly, } \frac{2000}{43} = 46.5116; \text{ CMIN} = 47 \text{ kHz.} \quad \text{T1MIN} = 2021 \text{ kHz}$$

$$\text{T2MIN} = 4089 \text{ kHz}$$

$$\frac{30000}{87} = 344.8276; \text{ CMAX} = 344 \text{ kHz. T1MAX} = 14792 \text{ kHz}$$

$$\text{T2MAX} = 29928 \text{ kHz}$$

It is now possible to calculate two lists of transmit test frequency pairs to yield a 3rd order intermod at the greatest common factor frequency with a QMAX of 65. For the case where $C = 2(T1) - T2$, a Type I intermod, there will be 299 combinations; C can be any value from 46 through 344 kHz. For the case where $C = T2 - 2(T1)$, a Type II intermod, there will be 298 combinations; C can be any value from 47 through 344 kHz. As can be seen from the table of transmit frequencies in terms of C, only half the QMAX values can be obtained with both Type I and Type II 3rd order intermods at the greatest common factor frequency.

4. Additional choices of the number of intermodulation frequencies in the standard AM broadcast band, 535-1605 kHz

It is impossible to derive a mathematical expression to generate easily the range of greatest common factors for a given number of intermods in the broadcast band while $QC = 3$. However, a series of cut-and-try calculations was made to cover any desired number from 1 through 20. The results are listed to include the minimum and maximum greatest common factors, the pertinent broadcast band intermods in terms of C as well as in frequency, and the order of each possible intermod. Because of the large GCF ranges, especially for the smaller numbers of intermods, only representative values are presented; therefore, the user of this table must calculate his own frequencies if they are missing in the listing for his choice of intermod number. This is a very simple procedure, involving merely the product of the greatest common factor and the coefficient of C for each broadcast band intermod.

Although this table was designed for use with transmit test frequencies yielding $QC = 3$, it is also useful for other values of QC. The only necessary change is the order designations for the intermod frequencies. If, for instance, $QC = 5$, the orders must be multiples of 5 instead of multiples of 3. For example, if the desired number of broadcast band intermods is 7 and $QC = 5$, the sequence of orders would become 20th, 25th, 30th, 35th, 40th, 45th, and 50th.

NUMBER OF BROADCAST INTERMODS VS GCF

Broadcast band = 535 to 1605 kHz

QC = 3, I; GCF = $2(T1) - T2$

or

QC = 3, II; GCF = $T2 - 2(T1)$

Number

1 GCF
MIN 803
804
to 3rd
1604
MAX 1605

Number

2	GCF	2C		GCF	2C	3C
MIN	535	1070		MIN	402	804
	536	1070			403	806
to	3rd	6th		to	6th	9th
	801	1602			533	1066
MAX	802	1604		MAX	534	1068

Number

3	GCF	2C	3C	4C
MIN	322	644	966	1288
	323	646	969	1292
to		6th	9th	12th
	400	800	1200	1600
MAX	401	802	1203	1604

Number

4	GCF	2C	3C	4C	5C
MIN	268	536	804	1072	1340
	269	538	807	1076	1345
to		6th	9th	12th	15th
	320	640	960	1280	1600
MAX	321	642	963	1284	1605

	GCF	3C	4C	5C	6C
MIN	230	690	920	1150	1380
	231	693	924	1155	1386
to		9th	12th	15th	18th
	266	798	1064	1330	1596
MAX	267	801	1068	1335	1602

Number

5	GCF	3C	4C	5C	6C	7C
MIN	201	603	804	1005	1206	1407
	202	606	808	1010	1212	1414
to		9th	12th	15th	18th	21st
	228	684	912	1140	1368	1596
MAX	229	687	916	1145	1374	1603

Number

6	GCF	GCF	3C	4C	5C	6C	7C	8C
MIN	179	537	716	895	1074	1253	1432	
	180	540	720	900	1080	1260	1440	
to		9th	12th	15th	18th	21st	24th	
	199	597	796	995	1194	1393	1592	
MAX	200	600	800	1000	1200	1400	1600	
	GCF	4C	5C	6C	7C	8C	9C	
MIN	161	644	805	966	1127	1288	1449	
	162	648	810	972	1134	1296	1458	
to		12th	15th	18th	21st	24th	27th	
	177	708	885	1062	1239	1416	1593	
MAX	178	712	890	1068	1246	1424	1602	

Number

7	GCF	4C	5C	6C	7C	8C	9C	10C
MIN	146	584	730	876	1022	1168	1314	1460
	147	588	735	882	1029	1176	1323	1470
to		12th	15th	18th	21st	24th	27th	30th
	159	636	795	954	1113	1272	1431	1590
MAX	160	640	800	960	1120	1280	1440	1600

Number

8	GCF	4C	5C	6C	7C	8C	9C	10C	11C
MIN	134	536	670	804	938	1072	1206	1340	1474
	135	540	675	810	945	1080	1215	1350	1485
to		12th	15th	18th	21st	24th	27th	30th	33rd
	144	576	720	864	1008	1152	1296	1440	1584
MAX	145	580	725	870	1015	1160	1305	1450	1595
	GCF	5C	6C	7C	8C	9C	10C	11C	12C
MIN	124	620	744	868	992	1116	1240	1364	1488
	125	625	750	875	1000	1125	1250	1375	1500
to		15th	18th	21st	24th	27th	30th	33rd	36th
	132	660	792	924	1056	1188	1320	1452	1584
MAX	133	665	798	931	1064	1197	1330	1463	1596

Number

9	GCF	5C	6C	7C	8C	9C	10C	11C	12C	13C
MIN	115	575	690	805	920	1035	1150	1265	1380	1495
	116	580	696	812	928	1044	1160	1276	1392	1508
to		15th	18th	21st	24th	27th	30th	33rd	36th	39th
	122	610	732	854	976	1098	1220	1342	1464	1586
MAX	123	615	738	861	984	1107	1230	1353	1476	1599

Number

10	GCF	5C	6C	7C	8C	9C
MIN	108	540	648	756	864	972
	109	545	654	763	872	981
to		15th	18th	21st	24th	27th
	113	565	678	791	904	1017
MAX	114	570	684	798	912	1026

C	10C	11C	12C	13C	14C
108	1080	1188	1296	1404	1512
109	1090	1199	1308	1417	1526
	30th	33rd	36th	39th	42nd
113	1130	1243	1356	1469	1582
114	1140	1254	1368	1482	1596

NOTE: GCF = 107 kHz is a special case.

The number of intermods between 535 and 1605 kHz is eleven.

However, see the remainder of the table continuing the GCF for ten intermods.

10

	GCF	6C	7C	8C	9C	10C
MIN	101	606	707	808	909	1010
	102	612	714	816	918	1020
to		18th	21st	24th	27th	30th
	105	630	735	840	945	1050
MAX	106	636	742	848	954	1060

C	11C	12C	13C	14C	15C
101	1111	1212	1313	1414	1515
102	1122	1224	1326	1428	1530
	33rd	36th	39th	42nd	45th
105	1155	1260	1365	1470	1575
106	1166	1272	1378	1484	1590

Number

11

GCF	5C	6C	7C	8C	9C	10C
107	535	642	749	856	963	1070
	15th	18th	21st	24th	27th	30th

C	11C	12C	13C	14C	15C
107	1177	1284	1391	1498	1605
	33rd	36th	39th	42nd	45th

	GCF	6C	7C	8C	9C	10C	11C
MIN	95	570	665	760	855	950	1045
	96	576	672	768	864	960	1056
to		18th	21st	24th	27th	30th	33rd
	99	594	693	792	891	990	1089
MAX	100	600	700	800	900	1000	1100

C	12C	13C	14C	15C	16C
95	1140	1235	1330	1425	1520
96	1152	1248	1344	1440	1536
	36th	39th	42nd	45th	48th
99	1188	1287	1386	1485	1584
100	1200	1300	1400	1500	1600

Number

12

GCF	6C	7C	8C	9C	10C	11C
MIN	90	540	630	720	810	900
to		18th	21st	24th	27th	30th
MAX	94	564	658	752	846	940

C	12C	13C	14C	15C	16C	17C
90	1080	1170	1260	1350	1440	1530
	36th	39th	42nd	45th	48th	51st
94	1128	1222	1316	1410	1504	1598

GCF	7C	8C	9C	10C	11C	12C
MIN	85	595	680	765	850	935
to		21st	24th	27th	30th	33rd
MAX	89	623	712	801	890	979

C	13C	14C	15C	16C	17C	18C
85	1105	1190	1275	1360	1445	1530
	39th	42nd	45th	48th	51st	54th
89	1157	1246	1335	1424	1513	1602

Number

13	GCF	7C	8C	9C	10C	11C	12C	13C			
	MIN	81	567	648	729	810	891	972	1053		
	to		21st	24th	27th	30th	33rd	36th	39th		
	MAX	84	588	672	756	840	924	1008	1092		
				C	14C	15C	16C	17C	18C	19C	
				81	1134	1215	1296	1377	1458	1539	
					42nd	45th	48th	51st	54th	57th	
				84	1176	1260	1344	1428	1512	1596	

Number

14	GCF	7C	8C	9C	10C	11C	12C	13C			
	MIN	77	539	616	693	770	847	924	1001		
	to		21st	24th	27th	30th	33rd	36th	39th		
	MAX	80	560	640	720	800	880	960	1040		
				C	14C	15C	16C	17C	18C	19C	20C
				77	1078	1155	1232	1309	1386	1463	1540
					42nd	45th	48th	51st	54th	57th	60th
				80	1120	1200	1280	1360	1440	1520	1600
	GCF	8C	9C	10C	11C	12C	13C	14C			
	MIN	73	584	657	730	803	876	949	1022		
	to		24th	27th	30th	33rd	36th	39th	42nd		
	MAX	76	608	684	760	836	912	988	1064		
				C	15C	16C	17C	18C	19C	20C	21C
				73	1095	1168	1241	1314	1387	1460	1533
					45th	48th	51st	54th	57th	60th	63rd
				76	1140	1216	1292	1368	1444	1520	1596

Number

15	GCF	8C	9C	10C	11C	12C	13C	14C	15C		
	MIN	70	560	630	700	770	840	910	980	1050	
	to		24th	27th	30th	33rd	36th	39th	42nd	45th	
	MAX	72	576	648	720	792	864	936	1008	1080	
				C	16C	17C	18C	19C	20C	21C	22C
				70	1120	1190	1260	1330	1400	1470	1540
					48th	51st	54th	57th	60th	63rd	66th
				72	1152	1224	1296	1368	1440	1512	1584

Number										
16	GCF	8C	9C	10C	11C	12C	13C	14C	15C	
	MIN 67	536	603	670	737	804	871	938	1005	
	to	24th	27th	30th	33rd	36th	39th	42nd	45th	
	MAX 69	552	621	690	759	828	897	966	1035	
		C	16C	17C	18C	19C	20C	21C	22C	23C
	67		1072	1139	1206	1273	1340	1407	1474	1541
			48th	51st	54th	57th	60th	63rd	66th	69th
	69		1104	1173	1242	1311	1380	1449	1518	1587
	GCF	9C	10C	11C	12C	13C	14C	15C	16C	
	MIN 65	585	650	715	780	845	910	975	1040	
	to	27th	30th	33rd	36th	39th	42nd	45th	48th	
	MAX 66	594	660	726	792	858	924	990	1056	
		C	17C	18C	19C	20C	21C	22C	23C	24C
	65		1105	1170	1235	1300	1365	1430	1495	1560
			51st	54th	57th	60th	63rd	66th	69th	72nd
	66		1122	1188	1254	1320	1386	1452	1518	1584

Number										
17	GCF	9C	10C	11C	12C	13C	14C	15C	16C	17C
	MIN 62	558	620	682	744	806	868	930	992	1054
	to	27th	30th	33rd	36th	39th	42nd	45th	48th	51st
	MAX 64	576	640	704	768	832	896	960	1024	1088
		C	18C	19C	20C	21C	22C	23C	24C	25C
	62		1116	1178	1240	1302	1364	1426	1488	1550
			54th	57th	60th	63rd	66th	69th	72nd	75th
	64		1152	1216	1280	1344	1408	1472	1536	1600

Number										
18	GCF	9C	10C	11C	12C	13C	14C	15C	16C	17C
	MIN 60	540	600	660	720	780	840	900	960	1020
	to	27th	30th	33rd	36th	39th	42nd	45th	48th	51st
	MAX 61	549	610	671	732	793	854	915	976	1037
		C	18C	19C	20C	21C	22C	23C	24C	25C
	60		1080	1140	1200	1260	1320	1380	1440	1500
			54th	57th	60th	63rd	66th	69th	72nd	75th
	61		1098	1159	1220	1281	1342	1403	1464	1525
	GCF	10C	11C	12C	13C	14C	15C	16C	17C	18C
	MIN 58	580	638	696	754	812	870	928	986	1044
	to	30th	33rd	36th	39th	42nd	45th	48th	51st	54th
	MAX 59	590	649	708	767	826	885	944	1003	1062
		C	19C	20C	21C	22C	23C	24C	25C	26C
	58		1102	1160	1218	1276	1334	1392	1450	1508
			57th	60th	63rd	66th	69th	72nd	75th	78th
	59		1121	1180	1239	1298	1357	1416	1475	1534

Number										
19	GCF	10C	11C	12C	13C	14C	15C	16C	17C	18C
MIN	56	560	616	672	728	784	840	896	952	1008
to		30th	33rd	36th	39th	42nd	45th	48th	51st	54th
MAX	57	570	627	684	741	798	855	912	969	1026
	C	19C	20C	21C	22C	23C	24C	25C	26C	27C
	56	1064	1120	1176	1232	1288	1344	1400	1456	1512
		57th	60th	63rd	66th	69th	72nd	75th	78th	81st
	57	1083	1140	1197	1254	1311	1368	1425	1482	1539
	C	28C								
	56	1568								
		84th								
	57	1596								

Number										
20	GCF	10C	11C	12C	13C	14C	15C	16C	17C	18C
MIN	54	540	594	648	702	756	810	864	918	972
to		30th	33rd	36th	39th	42nd	45th	48th	51st	54th
MAX	55	550	605	660	715	770	825	880	935	990
	C	19C	20C	21C	22C	23C	24C	25C	26C	27C
	54	1026	1080	1134	1188	1242	1296	1350	1404	1458
		57th	60th	63rd	66th	69th	72nd	75th	78th	81st
	55	1045	1100	1155	1210	1265	1320	1375	1430	1485
		28C	29C							
	54	1512	1566							
		84th	87th							
	55	1540	1595							

20										
	GCF	11C	12C	13C	14C	15C	16C	17C	18C	19C
MIN	52	572	624	676	728	780	832	884	936	988
to	33rd	33rd	36th	39th	42nd	45th	48th	51st	54th	57th
MAX	53	583	636	689	742	795	848	901	954	1007
	C	20C	21C	22C	23C	24C	25C	26C	27C	28C
	52	1040	1092	1144	1196	1248	1300	1352	1404	1456
		60th	63rd	66th	69th	72nd	75th	78th	81st	84th
	53	1060	1113	1166	1219	1272	1325	1378	1431	1484
	C	29C	30C							
	52	1508	1560							
		87th	90th							
	53	1537	1590							

etc.

Caution: it is necessary to use transmit frequency pairs where QMAX equals or exceeds the order of the highest broadcast band frequency. This point is discussed in the original text.

5. Fundamental expressions for calculating T1, T2, and QMAX where QC is greater than 3

The probability of selecting assignable transmit test frequencies for an RFI survey can be further increased by abandoning the requirement of $QC = 3$, even though the 3rd order case is still the most useful one. There are several rules for qualified intermodulation signal labels of a given order at the frequency equal to the greatest common factor. These are:

1. No combinations of M and N yielding a negative frequency
2. No combinations where M and N are equal
3. No combinations where M is less than N
4. Only Type I and Type II; no Type III where M and N are positive
5. M and N must be relatively prime

Using $QC = 5$ as an example, there are only four qualified combinations of M and N. Type I: $4(T1) - T2$, $3(T1) - 2(T2)$; Type II: $T2 - 4(T1)$, $2(T2) - 3(T1)$.

The following calculations for $QC = 5$ are typical of the procedure to be followed for any QC value. They are an obvious application of the rigid relationships in the Euclidean algorithm given in item two.

QC = 5, Type I

$C = 4(T1) - T2$

	M	N	$C = 4(T1) - T2$
$T2 = 3(T1) + B1$	-3	+1	$T1 = [A3+1]C$
$T1 = 1(B1) + C$	+4	-1	$T2 = [4(A3)+3]C$
$B1 = A3(C) + \text{zero}$	-U2	+U1	

$$QMAX = \frac{5(A3) + 4}{2}$$

$C = 3(T1) - 2(T2)$

	M	N	$C = 3(T1) - 2(T2)$
$T2 = 1(T1) + B1$	-1	+1	$T1 = [2(A3)+1]C$
$T1 = 2(B1) + C$	+3	-2	$T2 = [3(A3)+1]C$
$B1 = A3(C) + \text{zero}$	-U2	+U1	

$$QMAX = \frac{5(A3) + 2}{2}$$

QC = 5, Type II

$$C = T2 - 4(T1)$$

	<u>M</u>	<u>N</u>	<u>C = T2 - 4(T1)</u>
T2 = 4(T1) + C	-4	+1	T1 = (A2)C
T1 = A2(C) + zero	+U2	-U1	T2 = [4(A2)+1]C

$$QMAX = \frac{5(A2) + 1}{2}$$

$$C = 2(T2) - 3(T1)$$

	<u>M</u>	<u>N</u>	<u>C = 2(T2) - 3(T1)</u>
T2 = 1(T1) + B1	-1	+1	T1 = [2(A4)+1]C
T1 = 1(B1) + B2	+2	-1	T2 = [3(A4)+2]C
B1 = 1(B2) + C	-3	+2	
B2 = A4(C) + zero	+U2	-U1	QMAX = $\frac{5(A4) + 3}{2}$

Once the calculations are performed, it is unnecessary to retain the "A" factors in the resulting expressions for T1, T2, and QMAX. They can be replaced with X in the Type I case and Y in the Type II case. X and Y are positive, whole numbers arbitrarily chosen to fit the circumstances of interest to the RFI investigator.

The table lists the results of calculations conducted for QC values of 4, 5, 6, 7, 8, and 9. Still higher values are easily obtained.

ORDER TYPE	QC LABELS	T1	T2	QMAX
4, I	3(T1) - T2	[X+1]C	[3X+2]C	$\frac{4X+3}{2}$
4, II	T2 - 3(T1)	(Y)C	[3Y+1]C	$\frac{4Y+1}{2}$
5, I	4(T1) - T2	[X+1]C	[4X+3]C	$\frac{5X+4}{2}$
5, I	3(T1) - 2(T2)	[2X+1]C	[3X+1]C	$\frac{5X+2}{2}$
5, II	T2 - 4(T1)	(Y)C	[4Y+1]C	$\frac{5Y+1}{2}$
5, II	2(T2) - 3(T1)	[2Y+1]C	[3Y+2]C	$\frac{5Y+3}{2}$

6, I	$5(T1) - T2$	$[X+1]C$	$[5X+4]C$	$\frac{6X+5}{2}$
6, II	$T2 - 5(T1)$	$(Y)C$	$[5Y+1]C$	$\frac{6Y+1}{2}$
7, I	$6(T1) - T2$	$[X+1]C$	$[6X+5]C$	$\frac{7X+6}{2}$
7, I	$5(T1) - 2(T2)$	$[2X+1]C$	$[5X+2]C$	$\frac{7X+3}{2}$
7, I	$4(T1) - 3(T2)$	$[3X+1]C$	$[4X+1]C$	$\frac{7X+2}{2}$
7, II	$T2 - 6(T1)$	$(Y)C$	$[6Y+1]C$	$\frac{7Y+1}{2}$
7, II	$2(T2) - 5(T1)$	$[2Y+1]C$	$[5Y+3]C$	$\frac{7Y+4}{2}$
7, II	$3(T2) - 4(T1)$	$[3Y+2]C$	$[4Y+3]C$	$\frac{7Y+5}{2}$
8, I	$7(T1) - T2$	$[X+1]C$	$[7X+6]C$	$\frac{8X+7}{2}$
8, I	$5(T1) - 3(T2)$	$[3X+2]C$	$[5X+3]C$	$\frac{8X+5}{2}$
8, II	$T2 - 7(T1)$	$(Y)C$	$[7Y+1]C$	$\frac{8Y+1}{2}$
8, II	$3(T2) - 5(T1)$	$[3Y+1]C$	$[5Y+2]C$	$\frac{8Y+3}{2}$
9, I	$8(T1) - T2$	$[X+1]C$	$[8X+7]C$	$\frac{9X+8}{2}$
9, I	$7(T1) - 2(T2)$	$[2X+1]C$	$[7X+3]C$	$\frac{9X+4}{2}$
9, I	$5(T1) - 4(T2)$	$[4X+1]C$	$[5X+1]C$	$\frac{9X+2}{2}$
9, II	$T2 - 8(T1)$	$(Y)C$	$[8Y+1]C$	$\frac{9Y+1}{2}$
9, II	$2(T2) - 7(T1)$	$[2Y+1]C$	$[7Y+4]C$	$\frac{9Y+5}{2}$
9, II	$4(T2) - 5(T1)$	$[4Y+3]C$	$[5Y+4]C$	$\frac{9Y+7}{2}$

6. Simulated spectrum analyzer display, QC = 7, for C = 6(T1) - T2 and C = 4(T1) - 3(T2), QMAX near 50

From the table in item 5 the pertinent information for each of the two Type I the 7th order intermods at the greatest common factor frequency is

a C = 6(T1) - T2; T1 = [X+1]C, T2 = [6X+5]C

$$QMAX = \frac{7X + 6}{2}$$

b C = 4(T1) - 3(T2); T1 = [3X+1]C, T2 = [4X+1]C

$$QMAX = \frac{7X + 2}{2}$$

In a: If QMAX = 50, 7X + 6 = 100

$$7X = 94$$

$$X = 13.4286$$

With X = 13, $QMAX = \frac{7(13) + 6}{2} = 48$

With X = 14, $QMAX = \frac{7(14) + 6}{2} = 52$

Thus, for QMAX = 52

$$T1 = 15C, T2 = 89C$$

$$\frac{2000}{14} = 142.8571, \text{ so } CMIN = 143 \text{ kHz for}$$

$$T1MIN = 2145 \text{ kHz}$$

$$T2MIN = 12727 \text{ kHz}$$

$$\frac{30000}{143} = 209.7902, \text{ so simulated spectrum analyzer display must run from DC to at least}$$

210C to cover through 30000 kHz with CMIN.

In b: If QMAX = 50, 7X + 2 = 100

$$7X = 98$$

$$X = 14.0000, \text{ a whole number}$$

Thus, for QMAX = 50

$$T1 = 43C, T2 = 57C$$

$$\frac{2000}{43} = 46.5116, \text{ so } CMIN = 47 \text{ kHz for}$$

$$T1MIN = 2021 \text{ kHz}$$

$$T2MIN = 2679 \text{ kHz}$$

INTERMODULATION SPECTRUM CHART

SOLID:

T1 = 15C
T2 = 89C

QMAX = 51

QC = 7, 1

GCF = 6(T1) - T2

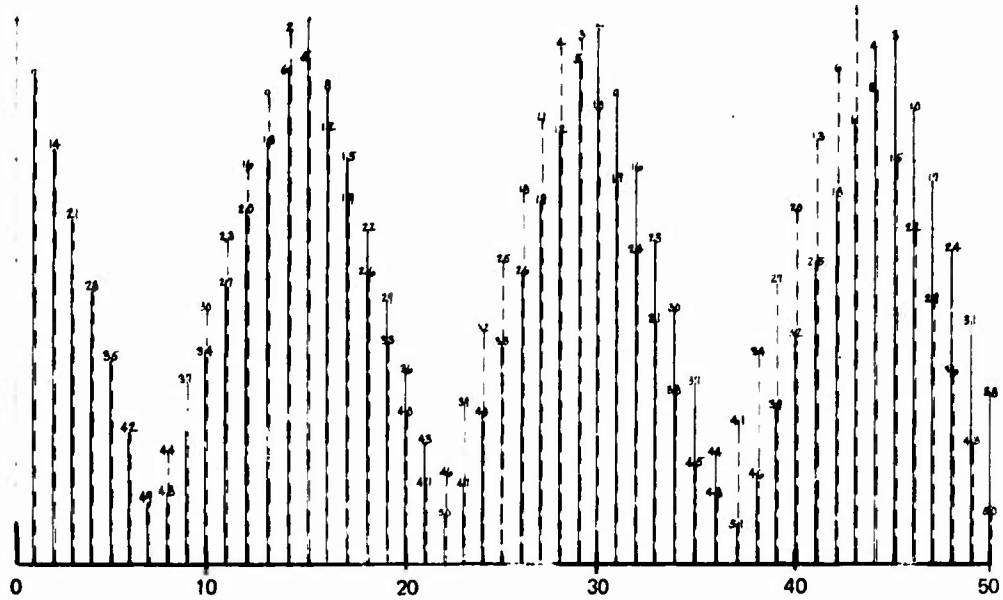
DASHED:

T1 = 43C
T2 = 57C

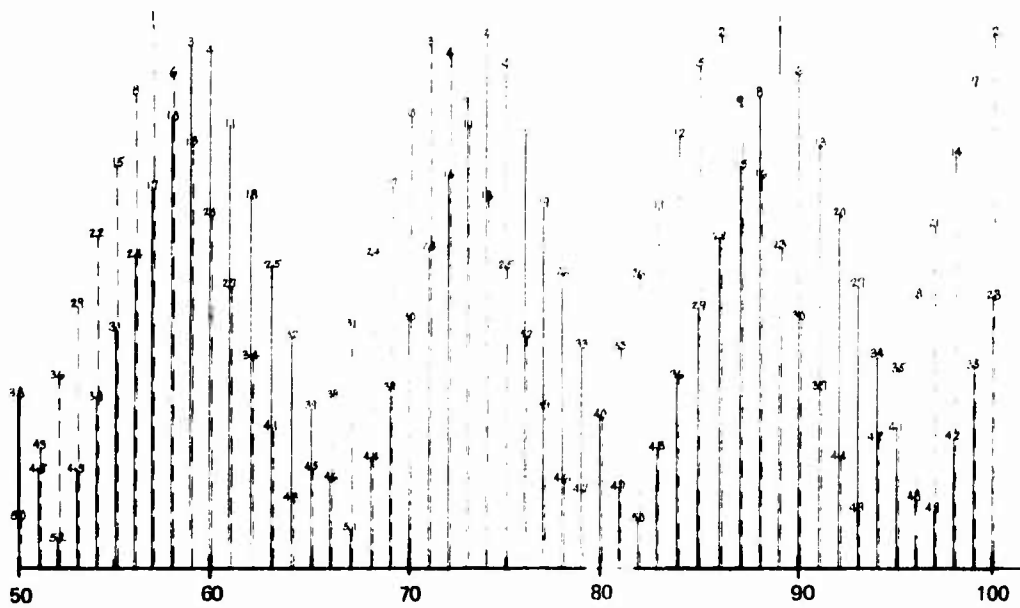
QMAX = 50

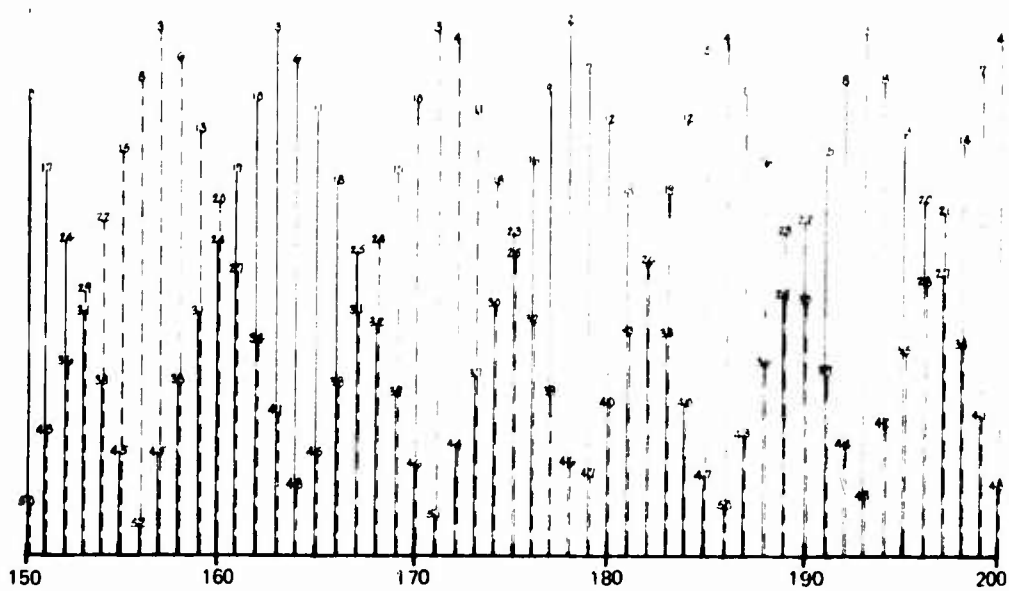
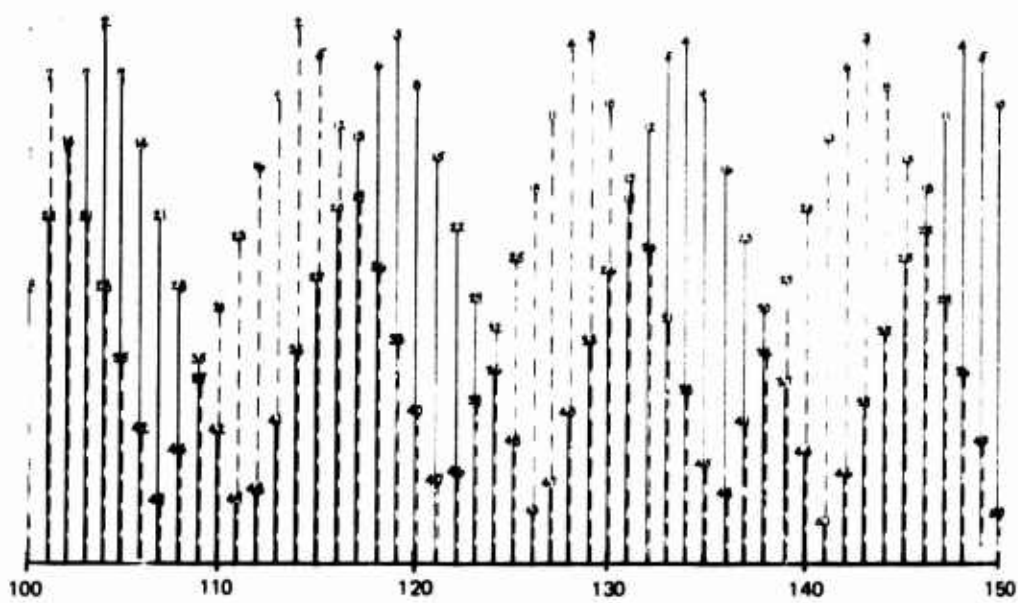
QC = 7, 1

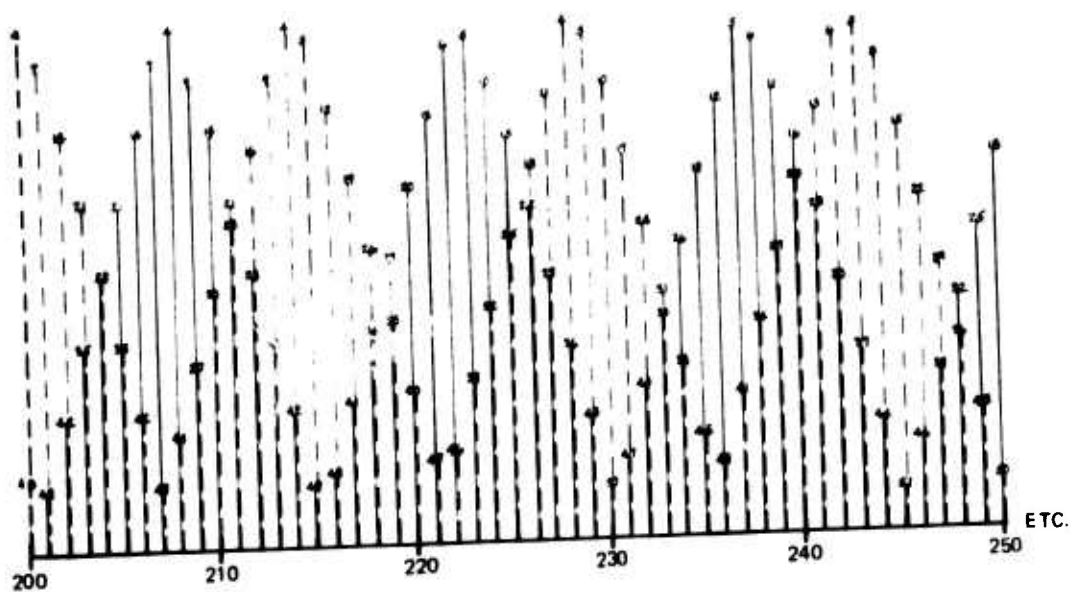
GCF = 4(T1) - 3(T2)



FREQUENCY DIVIDED BY GREATEST COMMON FACTOR







$\frac{30000}{47} = 638.2978$, so simulated spectrum analyzer display should run from DC to at least $639C$ to cover through 30000 kHz with C_{MIN} .

Note: The display only goes through $250C$, far short of the complete spectrum for $C = 4(T1) - 3(T2)$, because of the great amount of time and work required to make the calculations.

7. Choosing $T1$ and $T2$ to satisfy monitoring and source location conditions simultaneously

Conditions are: a. $QC = 3$, Type I or II

b. $QMAX = 41$

c. 17 broadcast band intermods

First Cut: For $QC = 3$, $QMAX = 41$: $T1 = 28C$, $T2 = 55C$

or $T1 = 27C$, $T2 = 55C$

For 17 broadcast band intermods: $C = 62, 63$, or 64 kHz

[Intermod at lowest frequency, $9C$, is 27th order.

Intermod at highest frequency, $25C$, is 75th order.]

$C = 62$ $T1 = 1736$, $T2 = 3410$

or $T1 = 1674$, $T2 = 3410$

$C = 63$ $T1 = 1764$, $T2 = 3465$

or $T1 = 1701$, $T2 = 3465$

$C = 64$ $T1 = 1792$, $T2 = 3520$

or $T1 = 1728$, $T2 = 3520$

The only reason why these six pairs of transmit frequencies cannot be used is that all $T1$'s are below 2000 kHz.

$$\frac{T1_{MIN}}{C_{MIN}} = \frac{2000}{62} = 32.2581, \text{ approximately } 33$$

$T1$ must be equal to, or greater than, $33C$. If $QMAX$ exceeds 49 , $T1$ exceeds 33 .

Second Cut: For $QMAX = 59$, $T1 = 40C$, $T2 = 79C$

or $T1 = 39C$, $T2 = 79C$

$C = 62$ $T1 = 2480$, $T2 = 4898$

or $T1 = 2418$, $T2 = 4898$

$C = 63$ $T1 = 2520$, $T2 = 4977$

or $T1 = 2457$, $T2 = 4977$

C = 64 T1 = 2560, T2 = 5056

or T1 = 2496, T2 = 5056

Note: In both the first cut, QMAX = 41, and the second cut, QMAX = 59, the spectrum of broadcast band intermods will be contaminated. The tabulated intermods above 806 and 1178 kHz, respectively, will be greater than QMAX. The only way to avoid that contamination is for QMAX to exceed 76.

Third Cut: For QMAX = 77, T1 = 52C, T2 = 103C

or T1 = 51C, T2 = 103C

C = 62 T1 = 3224, T2 = 6386

or T1 = 3162, T2 = 6386

C = 63 T1 = 3276, T2 = 6489

or T1 = 3213, T2 = 6489

C = 64 T1 = 3328, T2 = 6592

or T1 = 3264, T2 = 6592

Now the use of any one of these six pairs of transmit frequencies will yield

- a. QC = 3, Type I or II
- b. Difference in order between adjacent intermods equals 3 or less.
- c. QMAX = 77
- d. 17 broadcast band intermods
- e. Lowest broadcast band order is 27th
- f. Highest broadcast band order is 75th